FEDERAL AVIATION AGENCY

FURTHER APPLICATIONS of MOVING-COORDINATE PREDICTION MODELS to NORTH AMERICAN CYCLONES

JUNE 1963
7044-73

Interim Report
Technical Publication 31
Contract FAA/BRD-363

FURTHER APPLICATIONS OF MOVING-COORDINATE PREDICTION MODELS TO NORTH AMERICAN CYCLONES

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June 1963

Project 204-2

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FURTHER APPLICATIONS OF MOVING-COORDINATE PREDICTION MODELS TO NORTH AMERICAN CYCLONES, Frederick P. Ostby, Keith W. Veigas, and John E. Emerson. June 1963.
127 pp. incl. 3 app., 32 illus., 44 tbls., 15 refs.; interim rpt.
(FAA/BRD-363)

ABSTRACT

A moving-coordinate prediction-model technique applied to East Coast cyclones has been extended to predict cyclone behavior in most of North America for both summer and winter. Equations based on stratification, incorporation of past history, and addition of derived variables are developed from 833 cases. Comparison with equations based on unstratified data, no past history, and only simple variables shows that the latter set of equations is usually superior. This "base-technique" set of equations yields vector-position rms errors of 2.38, 4.26, and 5.96 deg lat and central-pressure rms errors of 4.28, 6.88, and 9.03 mb for 12, 24, and 36 hr when applied to 213 independent winter cases. Subsequent refinements achieve vector-position rms errors of 2.31, 4.10, and 5.88 deg lat and central-pressure rms errors of 4.19, 6.88, and 9.03 mb for the 3 time periods. Comparable results for climatology are 3.42, 6.13, and 8.34 deg lat for position and 4.83, 8.03, and 10.50 mb for central pressure. Results for summer cyclones are also presented.

Equations based on surface data only are developed and tested. They are useful whenever upper-air data are unavailable.

Worksheets for operational application of the technique are included.

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1.0 INTRODUCTION

This study represents an extension of previous work dealing with the prediction of cyclones over the eastern United States [14] and cyclones and anticyclones over Europe and Asia [7].

The method for predicting the movement and intensification of a cyclone consists of prediction equations derived statistically and based on a moving-coordinate system (a system in which predictor information is measured at points fixed with respect to the moving cyclone rather than at points fixed with respect to the earth).

Successful results on East Coast cyclones [14] (which showed the method to be competitive with the skill of synoptic forecasters), coupled with the relative simplicity with which a forecast could be completed on just a desk calculator, made the method feasible for operational application. During the past few winters, the prediction equations for East Coast cyclones have been used either operationally or experimentally as a forecast aid at several East Coast weather stations, including the National Weather Analysis Center (NWAC). This apparent acceptance of the method warranted extension of the study to derive prediction equations for other geographical areas.

The prediction of cyclone displacement and intensification is not an end in itself: it should provide information helpful in preparing a forecast of the associated weather.

The system of equations evolving from this study can be used operationally either manually with the aid of a desk calculator or completely automatically with the aid of a computer.

2.0 DEFINITION OF THE PROBLEM

The objective of this study was to derive equations for predicting the movement and intensification of surface cyclones over an area of North America for intervals of from 12 to 36 hr in advance.

2.1 Area Studied

The area defined in Fig. 2-1, which includes most of North America, was chosen for this study. Previous similar studies involved East Coast (United States) cyclones [14] and European and Asian cyclones and anticyclones [7].

2.2 Selection of Cases

Table 2-1 shows the number of cyclones selected for each of the zones of Fig. 2-1. The cyclones were selected by examining all 0000- and 1200-GCT surface charts* for the winters (November—March) of 1955-1956 through 1959-1960 and summers (May—September) of 1955 through 1959. A cyclone was accepted if it retained its identity for at least 36 hr in winter or 24 hr in summer.

The sample of cyclones selected for the winters of 1955-1956 through 1958-1959 was designated the dependent sample for derivation of winter-cyclone equations; the sample of summer cyclones for the summers of 1955 through 1958 was designated the dependent sample for derivation of summer-cyclone equations. Independent samples were made up of 1959-1960 winter cyclones and 1959 summer cyclones.

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*Microfilm copies of surface maps, analyzed by the National Weather Analysis Center, were used. From these, it was possible to construct maps showing individual cyclone tracks at 12-hr intervals, which served as the basis for selection.

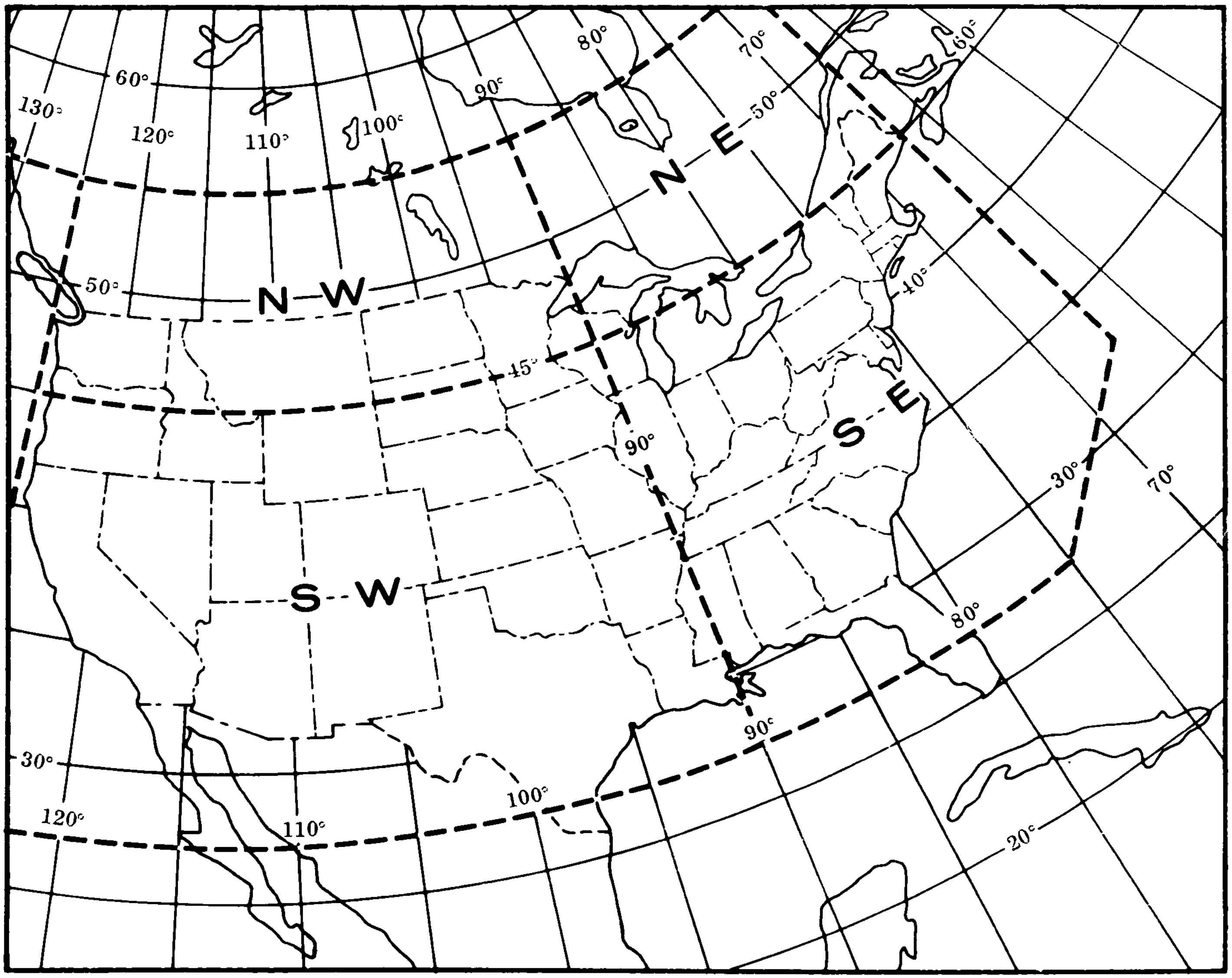

Fig. 2-1. The area for which cyclones were studied. The area is divided into four zones (northwest, northeast, southwest, and southeast) by latitude 45°N and longitude 90°W.

TABLE 2-1
NORTH AMERICAN CYCLONES SELECTED FOR STUDY,
1955-1960

Zone*	No. of winter cyclones			No. of summer cyclones		
	1955-1959†	1959-1960‡	Total	1955-1958†	1959‡	Total
NW	174	43	217	226	79	305
NE	154	34	188	199	38	237
SW	220	69	289	129	20	149
SE	285	67	352	146	32	178
All	833	213	1046	700	169	869

*See Fig. 2-1.
†Dependent sample.
‡Independent sample.

3.0 THE PREDICTION TECHNIQUE

3.1 Screening Regression

Multiple-linear-regression analysis was used to relate cyclone movement and intensification (predictands) with certain atmospheric variables (predictors) thought to have a bearing on cyclone behavior. The literature shows that many predictors have been suggested. Although it would seem desirable to utilize all predictors deemed important on the basis of previous theoretical, synoptic, and empirical work, Lorenz [5] points out that a prediction equation should contain few predictors in comparison with the size of the developmental sample; if there are too many, a relationship that fits the sample used to establish it is likely to fail when applied to a new sample. The screening procedure of Miller [6] was used in this study to limit the number of predictors.

The object of the screening procedure is to select from a set of possible predictors the subset that contributes most significantly and independently to reducing the variance of the predictand. From an array of possible predictors, the screening procedure selects first the one that has the highest linear correlation with the predictand in question. This predictor is then held constant, and partial-correlation coefficients between the predictand and each of the remaining predictors are examined; the predictor now associated with the highest coefficient is the second one selected. Additional predictors are chosen similarly until a selected predictor fails to explain a significant additional percentage of the remaining variance of the predictand.

The criterion of significance as applied to the screening procedure is not clear cut because the usual F-test methods [e.g., 12] are not applicable [6]. If a predictor is chosen at random from a group of predictors, an F-test is usually taken at the 95% level; this allows for a 1-in-20 chance of considering the predictor significant when in fact it is not. Because the screening procedure does not select predictors randomly, a more severe test is needed to specify a 1-in-20 chance. For his screening procedure, Miller suggested [6] that the critical F-value

be a function of the number of possible predictors. The F-test was used in this form in this study. After the significant predictors have been selected, the regression coefficients are obtained by the method of least squares.

3.2 The Moving-coordinate Grid

The grid for extracting predictor information accompanies the cyclone as it moves, so variables are measured at locations fixed with respect to the cyclone center rather than with respect to specific geographical locations. The grid is shown in Fig. 3-1. The gridpoint defined by the (k, ℓ)-location (10,5) is placed at the center of the cyclone, and the grid is oriented so that the line $k = 10$ coincides with the meridian passing through the center of the cyclone. In practice, grid placement and data tabulation were done by computer programs, and "analyzed maps" were on magnetic tape. On a polar stereographic projection with standard parallel at 60°N, the 17×13 array forms a set of evenly spaced points. On a map scale of 1:15,000,000, the grid interval is 1 in. This is the same interval as in the JNWP grid [2]. At 60°N, where the scale is true, one grid interval equals 381 km. The 221 points defined by this grid system were the ones used for basic predictor tabulation by superimposing the grid on analyzed maps of sea-level pressure, 700-mb height, and 500-mb height.

3.3 Predictands

Latitudinal displacement, longitudinal displacement, and change in central pressure were chosen (Table 3-1) as 12-, 24-, and 36-hr predictands for winter-cyclone equations and as 12- and 24-hr predictands for summer-cyclone equations. The same NWAC surface maps used to select the cases (see Section 2.2) were used as the source of predictand data.

3.4 Predictors Considered

Hemispheric-data tapes [11] were used as the primary source of predictor data. Special preprocessing programs (see Appendix A) automatically derived gridpoint arrays of pressure, height, and thickness data for each cyclone in the

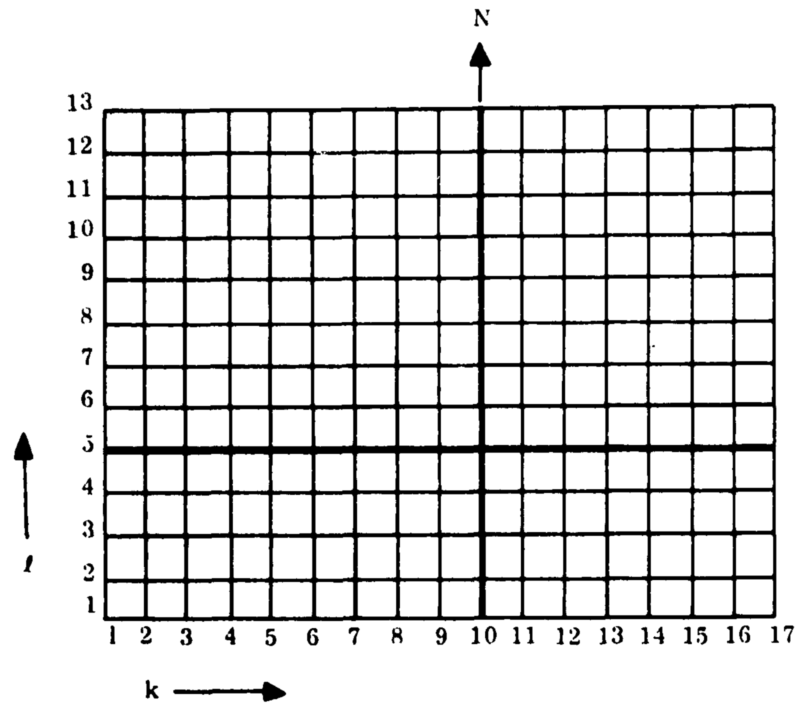

Fig. 3-1. Moving-coordinate grid overlay. Gridpoint (10,5) in the (k,ℓ)-array is always positioned at the center of the cyclone, and the grid is always oriented so that the line k 10 coincides with the meridian passing through the center of the cyclone. One grid interval equals one JNWP grid interval (381 km at 60°N).

TABLE 3-1
PREDICTANDS

Description	Symbol	Unit of measurement
12-hr northward displacement	$\hat{N}_{12}$	deg lat
12-hr eastward displacement	$\hat{E}_{12}$	deg lat
12-hr change in central pressure	$\hat{D}_{12}$	mb
24-hr northward displacement	$\hat{N}_{24}$	deg lat
24-hr eastward displacement	$\hat{E}_{24}$	deg lat
24-hr change in central pressure	$\hat{D}_{24}$	mb
36-hr northward displacement*	$\hat{N}_{36}$	deg lat
36-hr eastward displacement*	$\hat{E}_{36}$	deg lat
36-hr change in central pressure*	$\hat{D}_{36}$	mb

*For winter cyclones only.

TABLE 3-2
POSSIBLE PREDICTORS

Type	Symbol	Description	Unit of measurement	No. available*
A	ϕ	Present latitude of cyclone	deg lat	1
	λ	Present longitude of cyclone	deg long	1
	P	Sea-level pressure	mb	221
	ΔP	12-hr sea-level pressure change	mb	221
B	Z_7	700-mb height	10 ft	221
	ΔZ_7	12-hr 700-mb height change	10 ft	221
	Z	500-mb height	10 ft	221
	ΔZ	12-hr 500-mb height change	10 ft	221
	H_7	1000-700-mb thickness	10 ft	221
	ΔH_7	12-hr 1000-700-mb thickness change	10 ft	221
	H	1000-500-mb thickness	10 ft	221
	ΔH	12-hr 1000-500-mb thickness change	10 ft	221
C	η	500-mb absolute vorticity	10^{-5} sec^{-1}	165
	$\Delta\eta$	12-hr vorticity change	10^{-5} sec^{-1}	165
	ζ_T	Thermal vorticity (1000-500-mb)	10^{-5} sec^{-1}	165
	$\Delta\zeta_T$	12-hr thermal vorticity change	10^{-5} sec^{-1}	165
	A_η	500-mb vorticity advection	10^{-10} sec^{-2}	117
	A_{H7}	1000-700-mb thickness advection	10^{-4} ft sec^{-1}	165
	A_H	1000-500-mb thickness advection	10^{-4} ft sec^{-1}	165
	$A_{\zeta T}$	Thermal vorticity advection	10^{-10} sec^{-2}	117
	L	Laplacian of the 1000-500-mb thickness advection	10^{-16} ft^{-1} sec^{-1}	117
	u_7, v_7, $\lvert V_7\rvert$	700-mb geostrophic wind	10 ft sec^{-1}	3
	Δu_7, Δv_7, $\Delta\lvert V_7\rvert$	12-hr 700-mb geostrophic wind change	10 ft sec^{-1}	3
	u, v, $\lvert V\rvert$	500-mb geostrophic wind	10 ft sec^{-1}	3
	Δu, Δv, $\Delta\lvert V\rvert$	12-hr 500-mb geostrophic wind change	10 ft sec^{-1}	3
	u', v', $\lvert V'\rvert$	1000-500-mb thermal wind	10 ft sec^{-1}	3
	$\Delta u'$, $\Delta v'$, $\Delta\lvert V'\rvert$	12-hr 1000-500-mb thermal wind change	10 ft sec^{-1}	3
	u'_7, v'_7, $\lvert V'_7\rvert$	1000-700-mb thermal wind	10 ft sec^{-1}	3
	$\Delta u'_7$, $\Delta v'_7$, $\Delta\lvert V'_7\rvert$	12-hr 1000-700-mb thermal wind change	10 ft sec^{-1}	3
Past-history	$\Delta\phi$	Previous 6-hr latitude change	deg lat	1
	$\Delta\lambda$	Previous 6-hr longitude change	deg lat	1
	ΔP_c	Previous 6-hr central-pressure change	mb	1

*Total of all four types is 3580.

developmental sample. These basic predictors are represented by types A and B in Table 3-2.

More "complex" predictors (type C, Table 3-2), formed from various combinations of the basic predictors, were generated on the IBM 7090 by conventional finite-difference procedures. The Laplacian of the 1000—500-mb thickness advection was suggested by Petterssen [9] as important to cyclone development. Advection of thermal vorticity by the thermal wind is also known as the "development" or "baroclinic" term [13]. East-west and north-south components and magnitudes of the geostrophic wind over the cyclone were derived at 700 and 500 mb to be used as measures of steering. Various steering techniques [1, 4, 8, 10] for forecasting the displacement of cyclones are widely used by practicing forecasters. Twelve-hour changes in thermal wind components were also computed to include steering tendencies [e.g., 3] as possible predictors.

Miller's screening-regression technique (as programmed for the IBM 7090) could simultaneously examine only 175 predictors, so the number of possible predictors was reduced subjectively before screening regression was applied. Section 5.0 discusses the reduction in more detail.

3.5 Gross-error Checking

An important preliminary step in the preparation of the data for the prediction experiments was a systematic man-machine search for and correction of gross errors. Suspicious gridpoint values of parameters were identified by a series of tests performed by the IBM 7090, and listings of these values were compared with microfilm copies of manuscript maps; where necessary, corrections were made to the data filed on magnetic tapes. The details of the computer programs, data-handling procedures, and error-checking procedures are given in Appendix A.

4.0 SYNOPTIC CLIMATOLOGY

Preparatory to deriving prediction equations for cyclones, their climatological characteristics and their supposedly related atmospheric variables were computed to aid in suggesting possible predictors. To determine the difference in characteristics for different regions of the area (Fig. 2-1), the means and standard deviations of all predictands and possible predictors were computed for the entire area (unstratified) and for regions within the area (stratified).

4.1 Winter Cyclones

Table 4-1 contains the means and standard deviations of the northward and eastward displacements and changes in central pressure of 833 North American winter cyclones. Figure 4-1 depicts the mean cyclone tracks in each of the four zones. The southeastern-zone cyclones undergo the maximum deepening (12 mb in 36 hr); the northwestern zone shows no change in central pressure for 36 hr. These two zones also contained the faster-moving cyclones (about 25 knots); the southwestern- and northeastern-zone cyclones averaged about 20 knots. The southeastern zone, of course, contains cyclones developing along the East Coast, where the thermal contrast between land and water is conducive to cyclone intensification. The northwestern zone contains the cyclones that develop in southwestern Canada. The characteristic southeastward track of these "Alberta" cyclones shows up in the mean track for northwestern-zone cyclones.

The associated mean maps of pressure, height, and thickness are shown as Figs. 4-2 through 4-7.

The differences among the four sea-level pressure maps (Fig. 4-2) are not very spectacular. The mean locations and central pressures for the cyclones are given in Table 4-2. The northeastern-zone cyclones are generally the deepest because this zone contains many of the more mature cyclones, which have already undergone most of their development. Most of the zones have an area of high pressure to the west and northwest of the cyclone. The main exception is the northwestern zone, where the high pressure to the west is very weak and another

TABLE 4-1
CHARACTERISTICS OF WINTER CYCLONES OVER NORTH AMERICA,
1955-1959 (DEPENDENT SAMPLE)

Zone	Forecast interval, hr	Observed northward displacement, deg lat		Observed eastward displacement, deg lat		Observed change in central pressure, mb	
		Mean*	Std dev	Mean†	Std dev	Mean‡	Std dev
NW	12	-0.94	2.52	-4.83	2.13	-0.23	4.62
	24	-1.31	4.42	-9.33	3.62	-0.17	7.35
	36	-1.00	5.83	-13.39	4.99	[illegible]	9.20
NE	12	1.67	2.57	-3.79	2.36	-1.23	4.70
	24	3.26	4.45	-7.35	4.06	-2.45	8.46
	36	4.78	5.80	-10.66	6.56	-4.29	12.33
SW	12	0.03	2.80	-3.83	2.38	-0.99	4.50
	24	0.87	4.67	-7.82	4.35	-1.65	7.30
	36	2.13	6.32	-11.73	6.11	-2.55	10.26
SE	12	2.25	2.08	-4.25	2.64	-5.02	5.83
	24	4.59	3.76	-8.32	4.85	-9.50	10.23
	36	6.98	5.21	-11.36	6.96	-12.[illegible]	13.85
All	12	0.96	2.79	-4.18	2.46	-2.2[illegible]	5.44
	24	2.09	4.36	-8.24	4.47	-4.16	9.47
	36	3.57	6.32	-11.09	6.35	-5.55	12.76

*Negative values represent southward displacement.
†Negative values represent eastward displacement.
‡Negative values represent deepening.

TABLE 4-2
MEAN LOCATIONS AND CENTRAL PRESSURES
OF WINTER CYCLONES,
1955-1959 (DEPENDENT SAMPLE)

Zone	Mean lat, °N	Mean long, °W	Mean central press, mb
NW	50.5	104.1	1001
NE	49.7	80.5	996
SW	37.6	101.5	1001
SE	37.1	77.5	1002

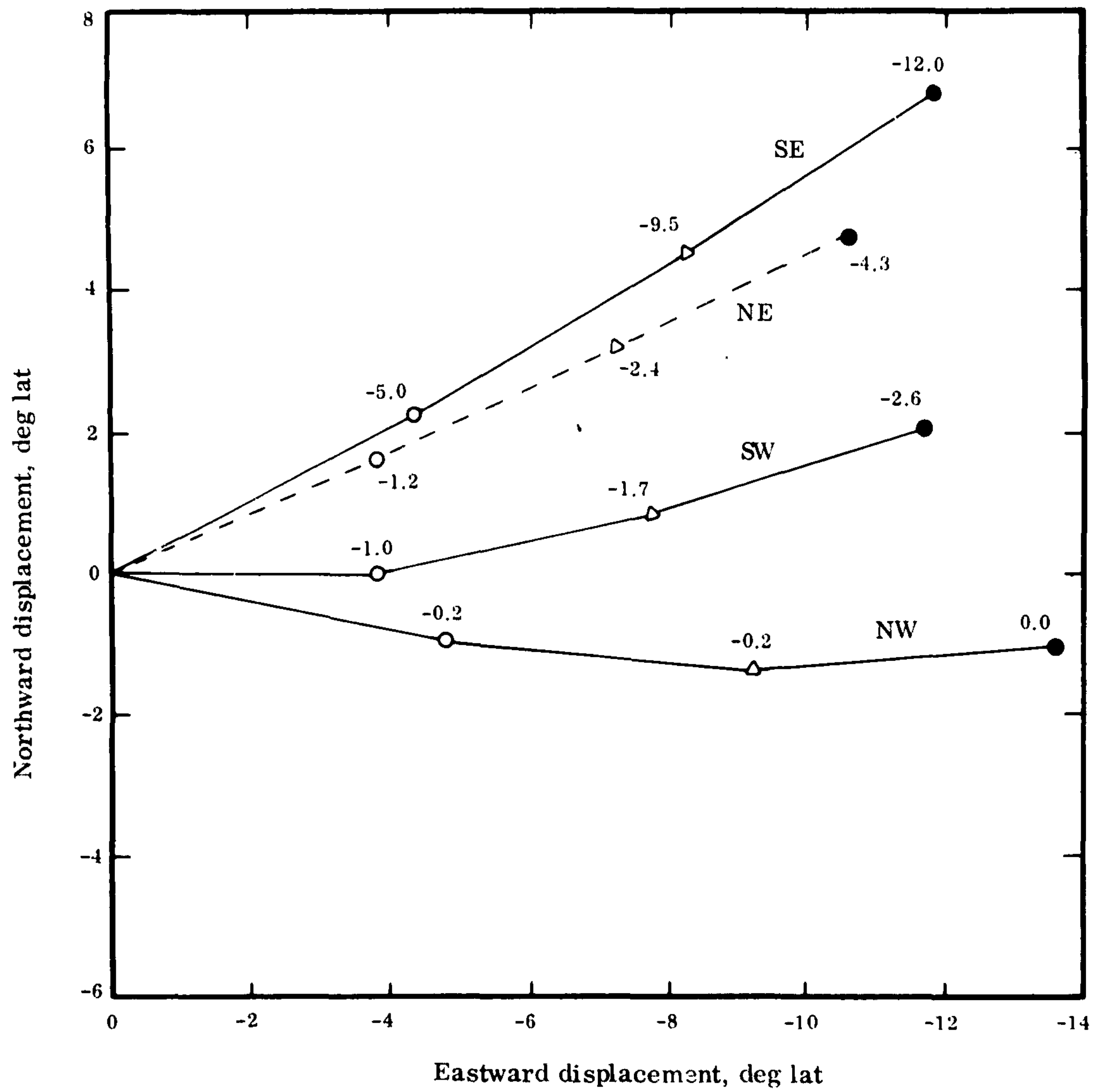

Fig. 4-1. Mean tracks of winter cyclones in North America by zone, 1955-1959 (dependent sample). O 12-hr displacement; △ 24-hr displacement; ● 36-hr displacement. Value adjacent to symbol refers to mean change in central pressure (millibars).

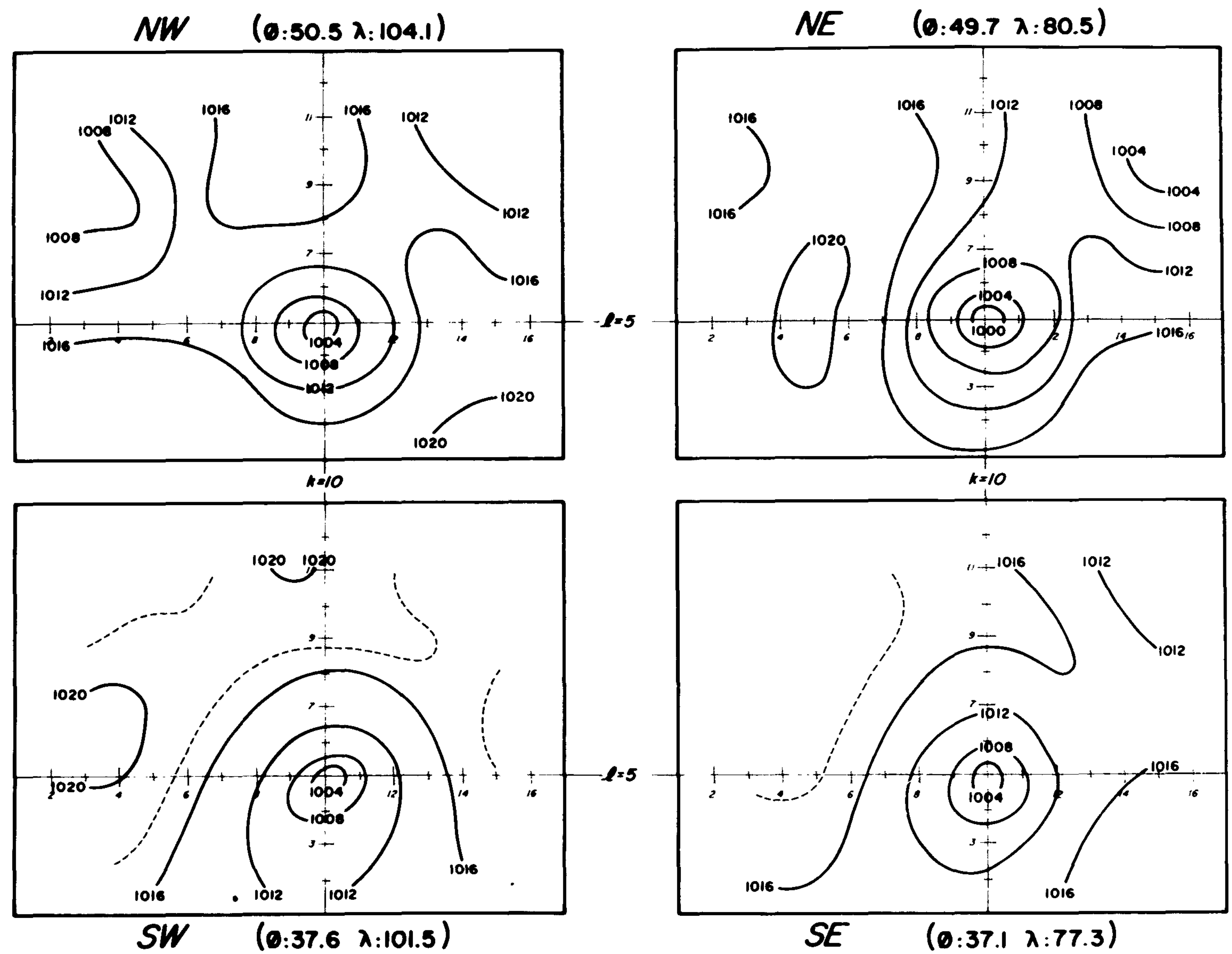

Fig. 4-2. Mean maps of sea-level pressure for winter cyclones in North America, 1955-1959 (dependent sample). Isobars are labeled in millibars.

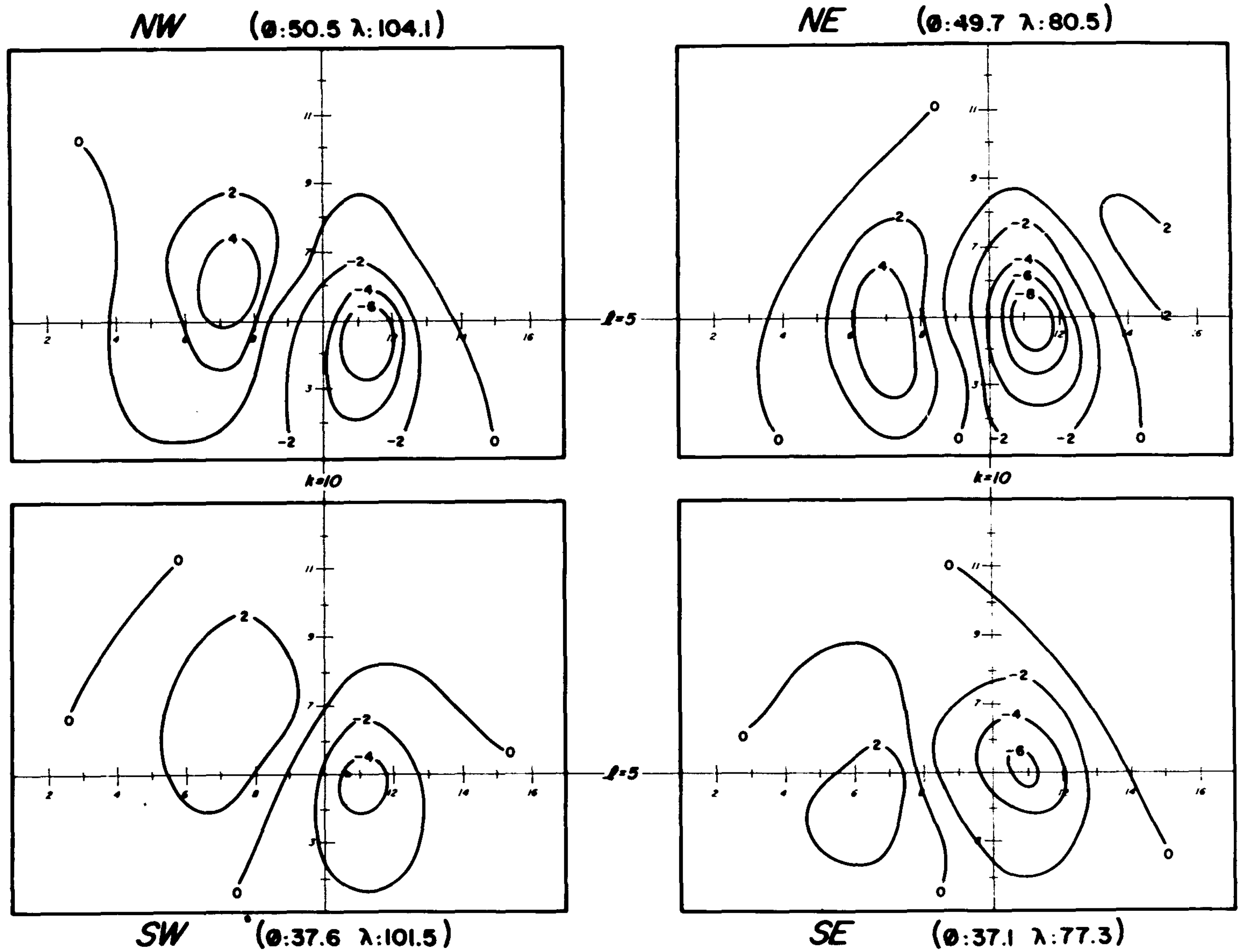

Fig. 4-3. Mean maps of 12-hr sea-level pressure change for winter cyclones in North America, 1955-1959 (dependent sample). Isallobars are labeled in millibars.

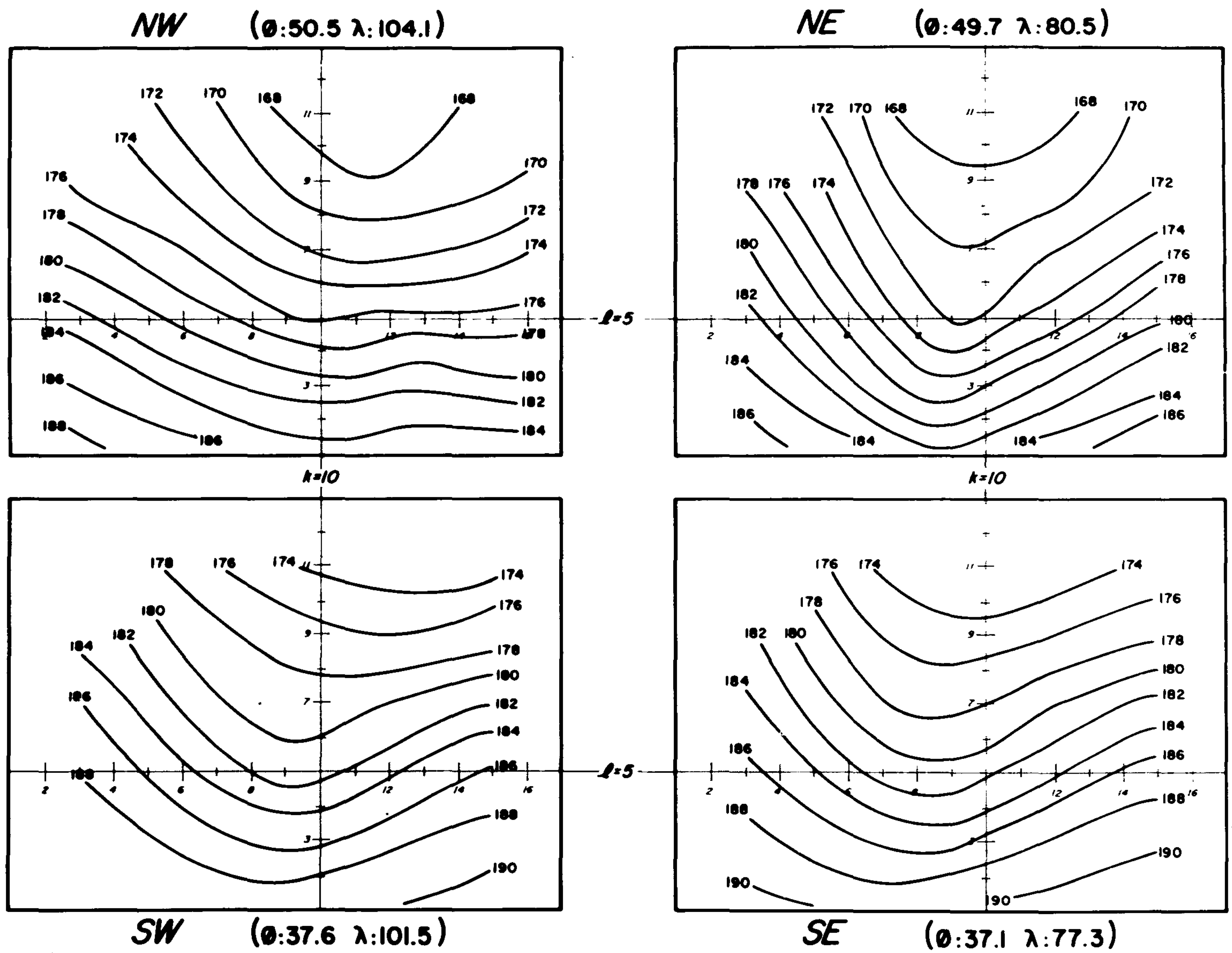

Fig. 4-4. Mean maps of 500-mb height for winter cyclones in North America, 1955-1959 (dependent sample). Isohypses are labeled in tens of feet.

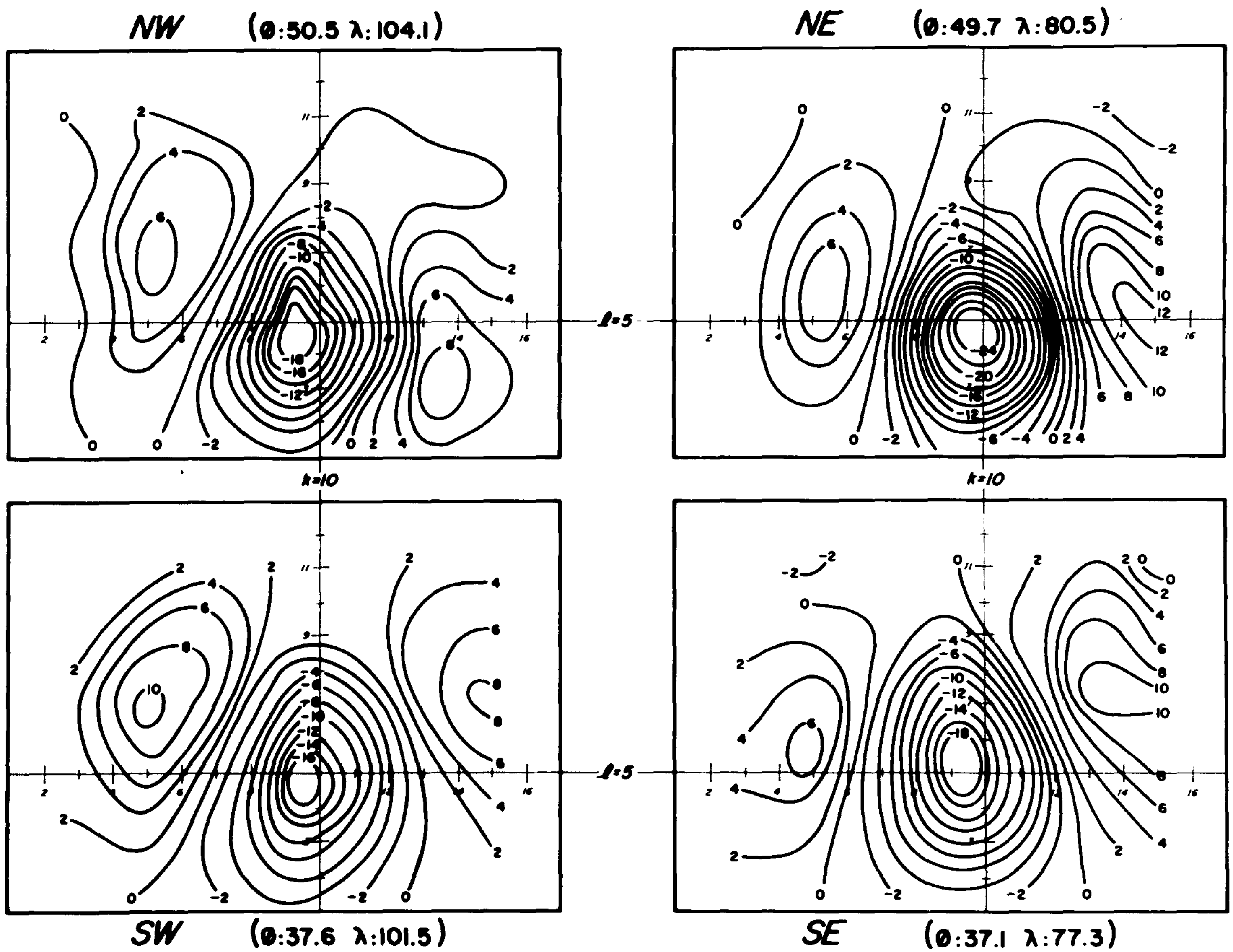

Fig. 4-5. Mean maps of 12-hr 500-mb height change for winter cyclones in North America, 1955-1959 (dependent sample). Isallohypses are labeled in tens of feet.

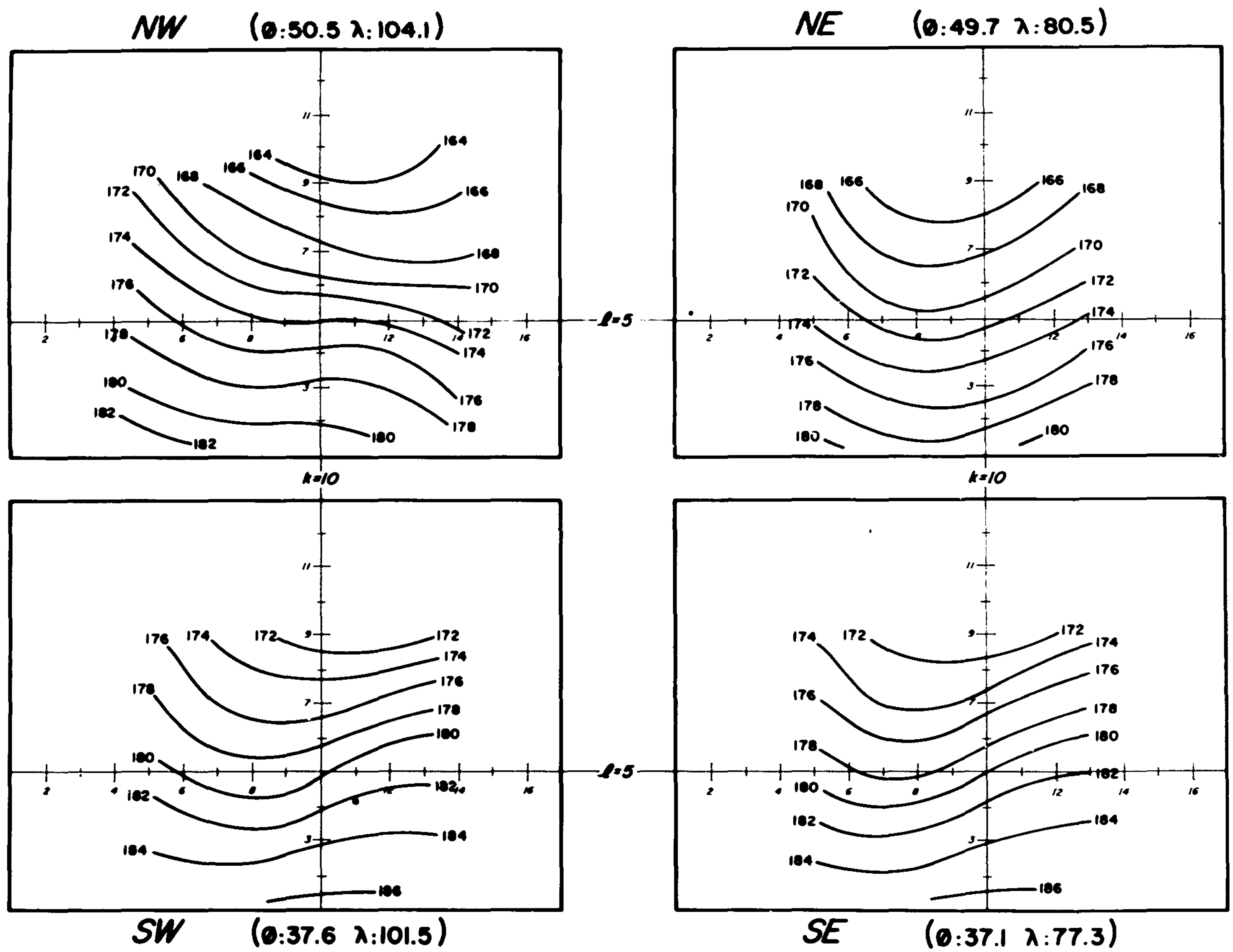

Fig. 4-6. Mean maps of 1000–500-mb thickness for winter cyclones in North America, 1955-1959 (dependent sample). Isopachs are labeled in tens of feet.

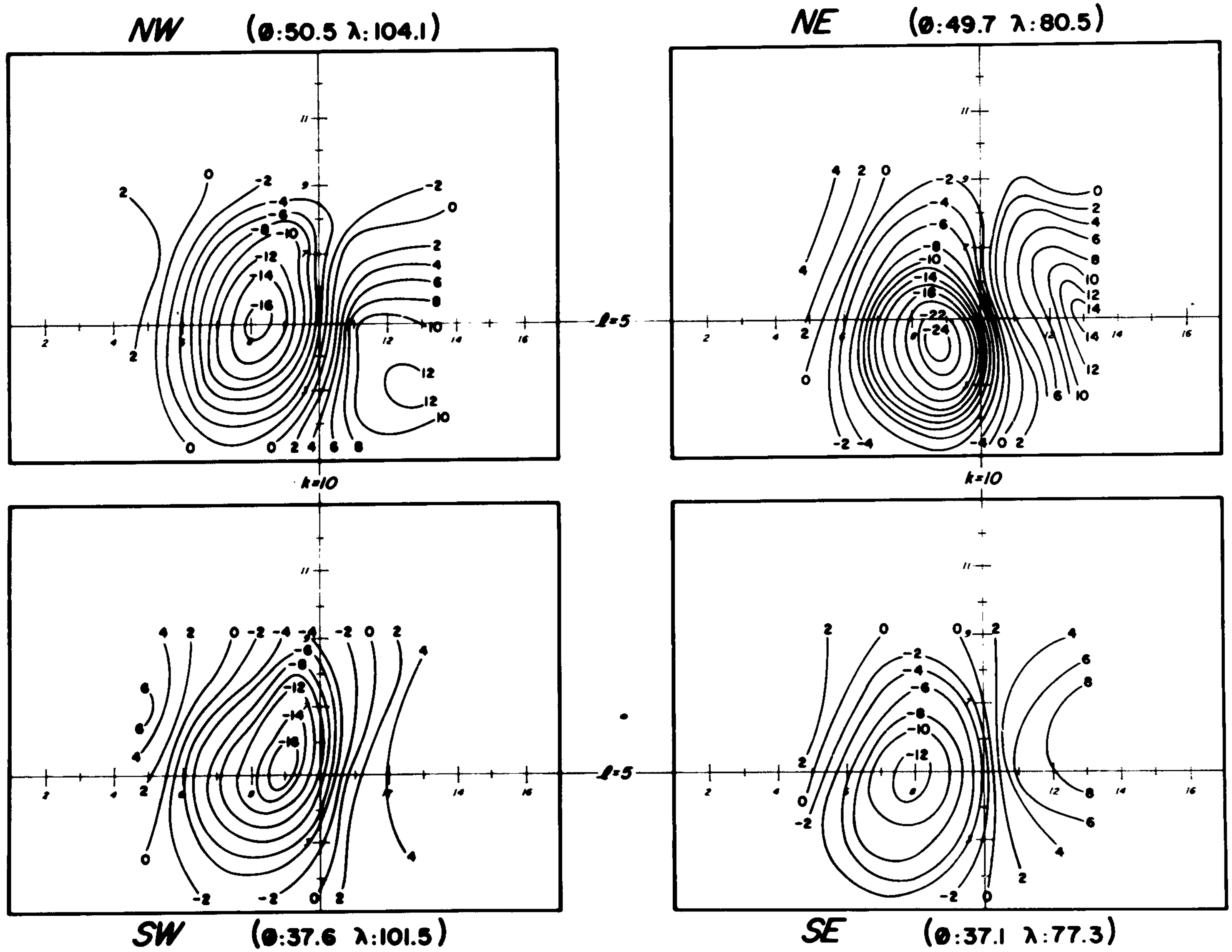

Fig. 4-7. Mean maps of 12-hr 1000–500-mb thickness change for winter cyclones in North America, 1955-1959 (dependent sample). Isallopachs are labeled in tens of feet.

cyclone is evident in the upper-left corner. This is undoubtedly due to cyclonic activity in the Gulf of Alaska. Similarly, the low pressure in the upper-right corner of the northeastern zone is due to the Icelandic Low.

The 12-hr pressure-change maps (Fig. 4-3) are all similar in that each has a katallobaric center east of the cyclone and an anallobaric center west. The magnitude of these centers is larger in the two northern zones than in the southern.

At 500 mb (Fig. 4-4), the cyclone is located under a southwesterly flow in all zones except the northwestern, where the flow is westerly. This is probably a result of many cases of cyclones imbedded in a northwesterly flow pattern, which is not uncommon for that zone. In the other zones, where the flow is southwesterly, the trough line is located 200 or 300 naut mi upstream from the cyclone. The most pronounced trough occurs in the northeastern zone.

The maximum 12-hr height falls at 500 mb (Fig. 4-5) are located about 200 naut mi west of the cyclone in all four zones. The general pattern shows rise centers east and west of the falls for each zone. The greatest fall center, in excess of 240 ft, is in the northeastern zone. The rise center ahead of the cyclone is toward the northeast or east—except in the northwestern zone, where it is toward the southeast. The rather small magnitudes of both maxima and minima can be accounted for only by the apparent variability in location of the rise and fall centers among individual cases, tending to damp them in the mean.

The orientation of the 1000—500-mb thickness contours (Fig. 4-6) is similar to the 500-mb height field (Fig. 4-4). The absolute values of the thickness contours are about 600 ft lower in the northern zones than the southern, which is simply a reflection of the temperature variation with latitude in the mid-troposphere.

The 12-hr thickness change for the 1000—500-mb layer (Fig. 4-7) is proportional to the change in mean temperature for the layer. It is likely that this temperature change provides a rough estimate of the thermal advection for the layer. In the mean-thickness-change maps, negative values refer to

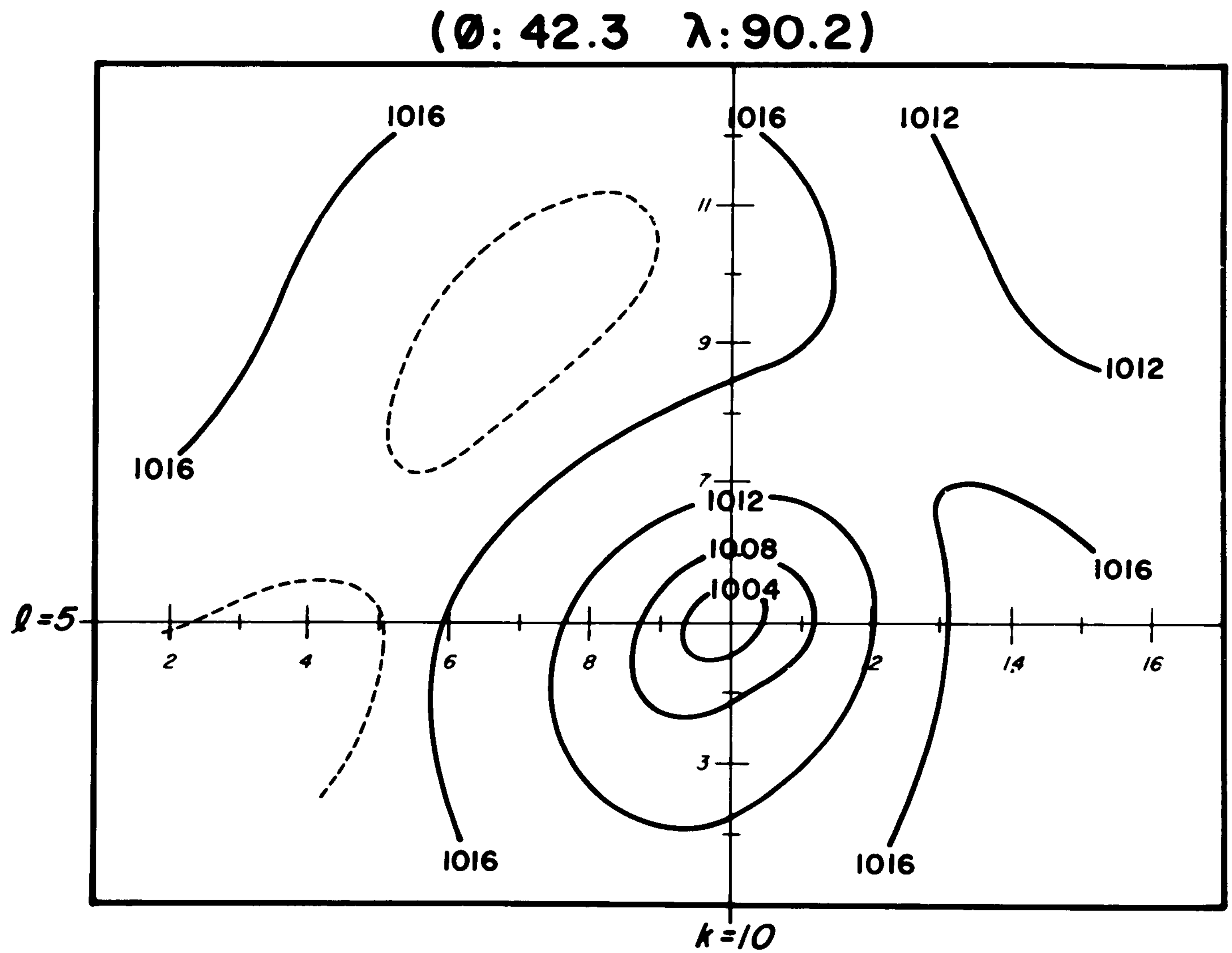

Fig. 4-8. Pooled mean map of sea-level pressure for winter cyclones in North America. 1955–1959 (dependent sample). Isobars are labeled in millibars.

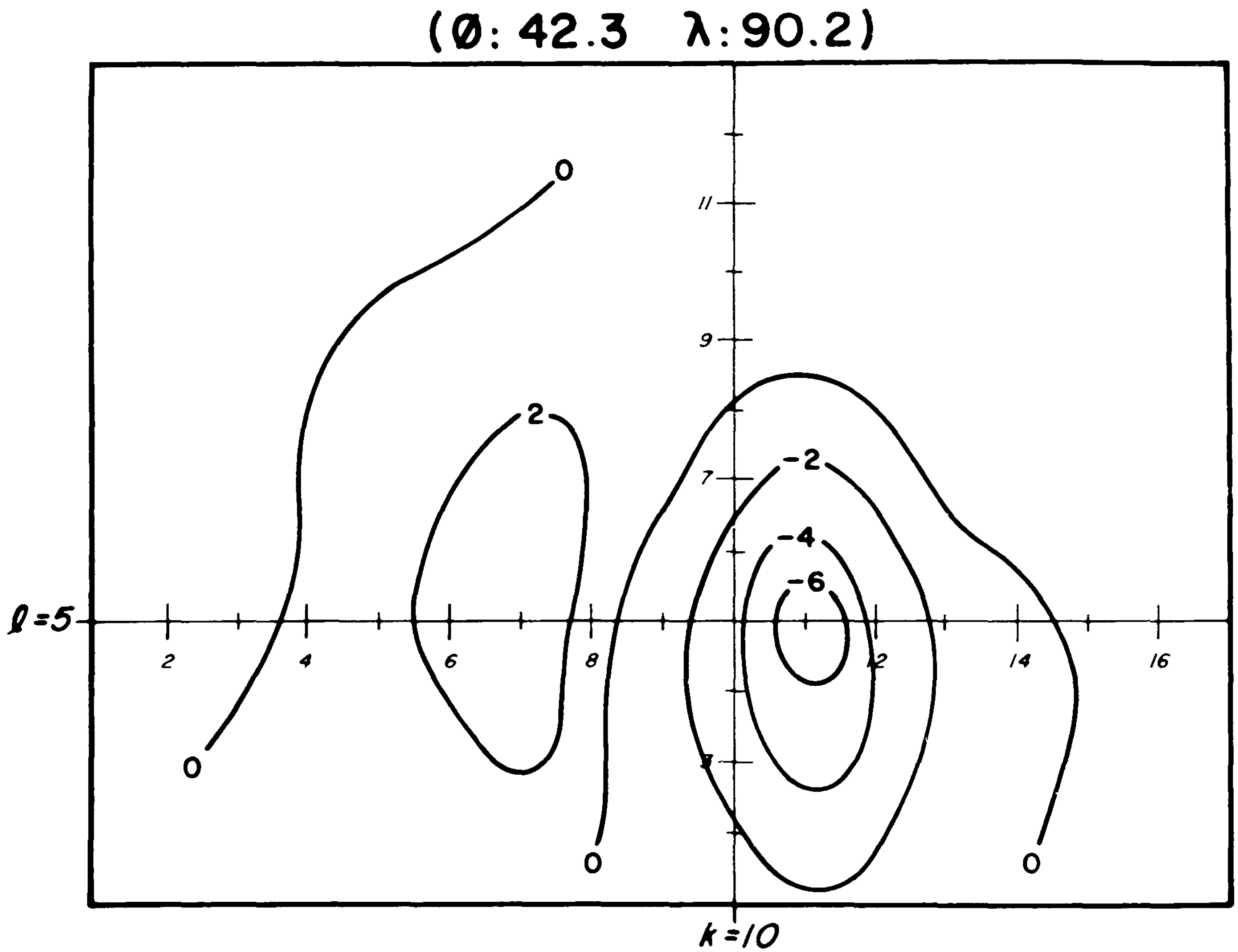

Fig. 1-9. Pooled mean map of 12-hr pressure change for winter cyclones in North America, 1955-1959 (dependent sample). Isallobars are labeled in millibars.

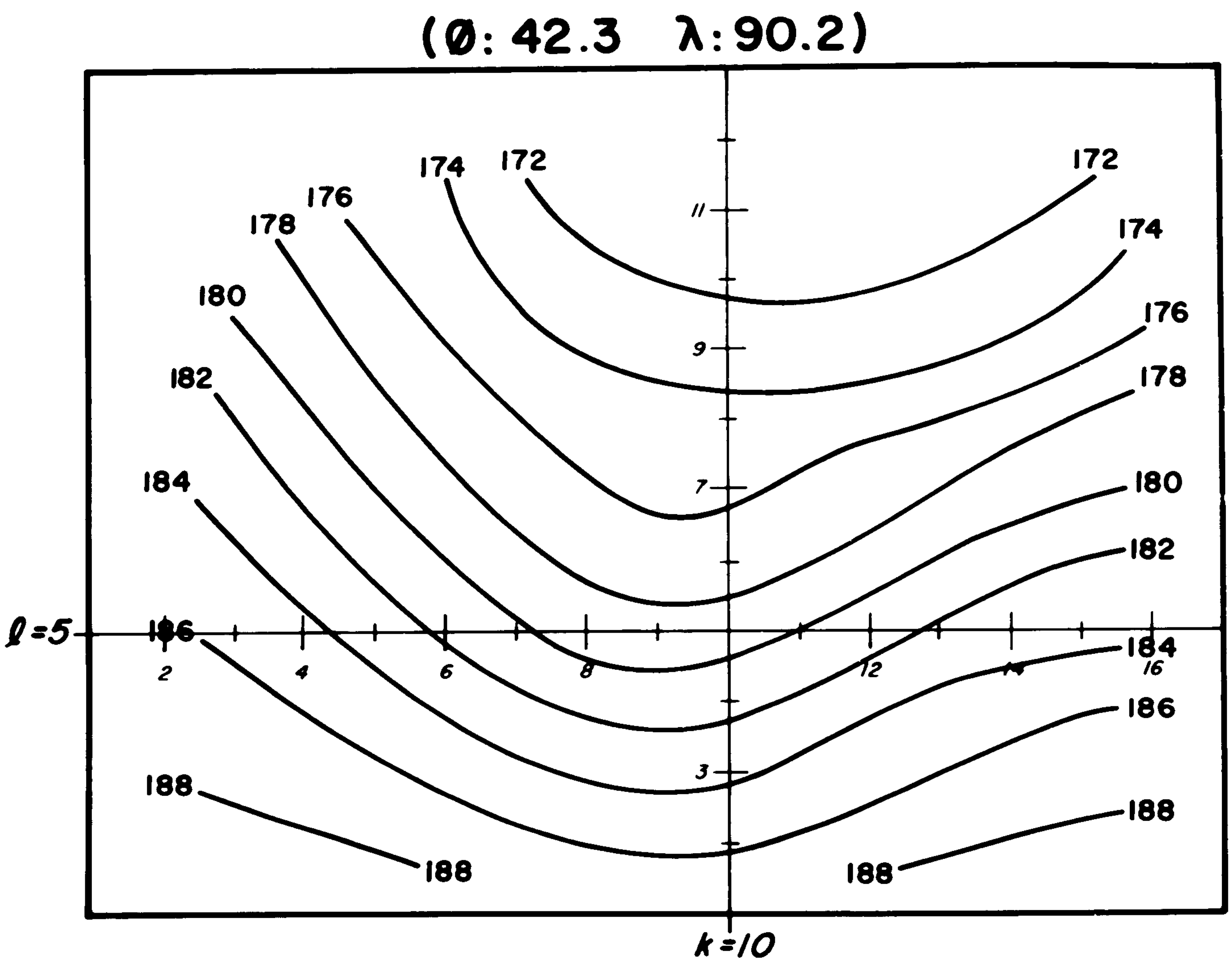

Fig. 4-10. Pooled mean map of 500-mb height for winter cyclones in North America, 1955-1959 (dependent sample). Isohypses are labeled in tens of feet.

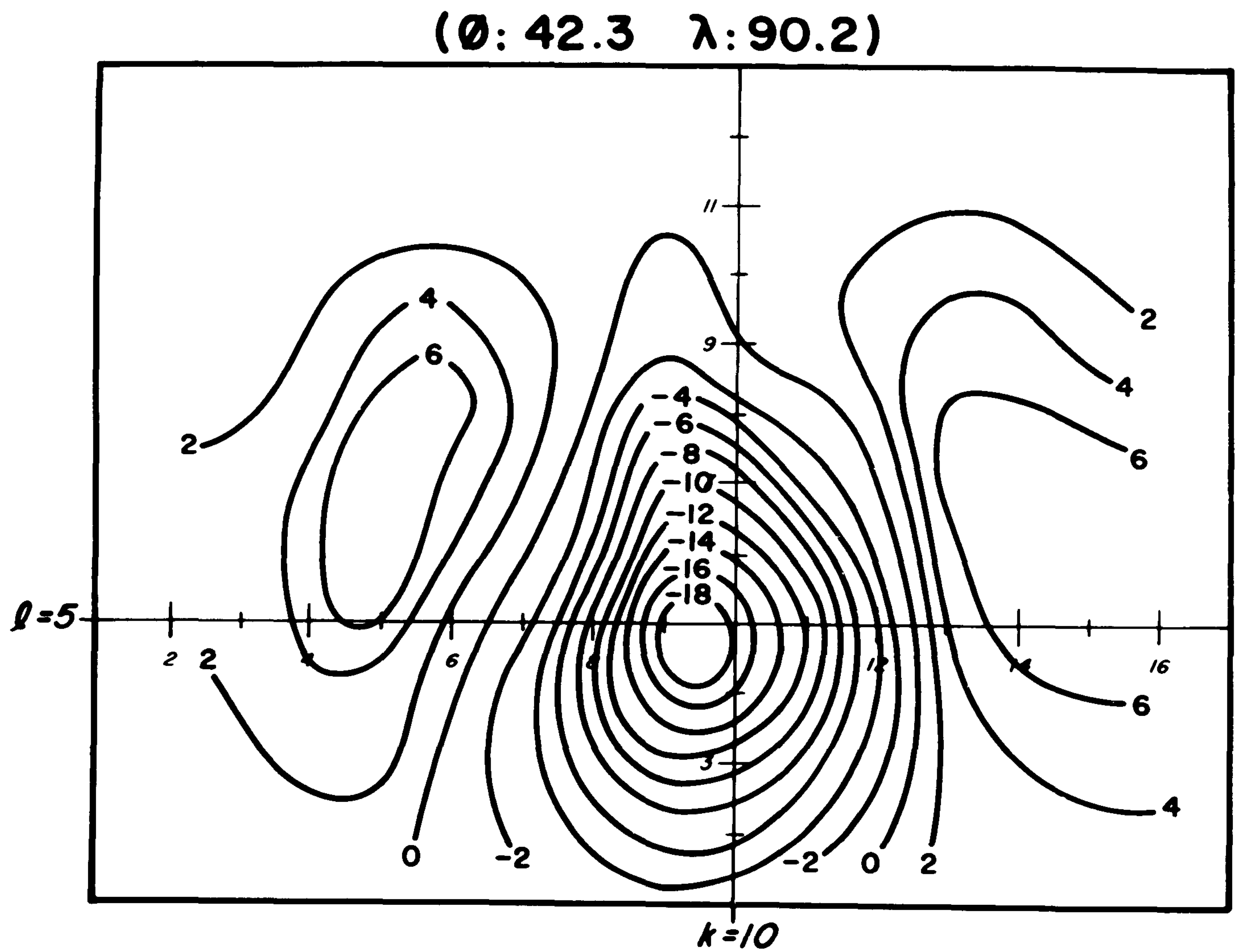

Fig. 4-11. Pooled mean map of 12-hr 500-mb height change for winter cyclones in North America, 1955-1959 (dependent sample). Isallohypses are labeled in tens of feet.

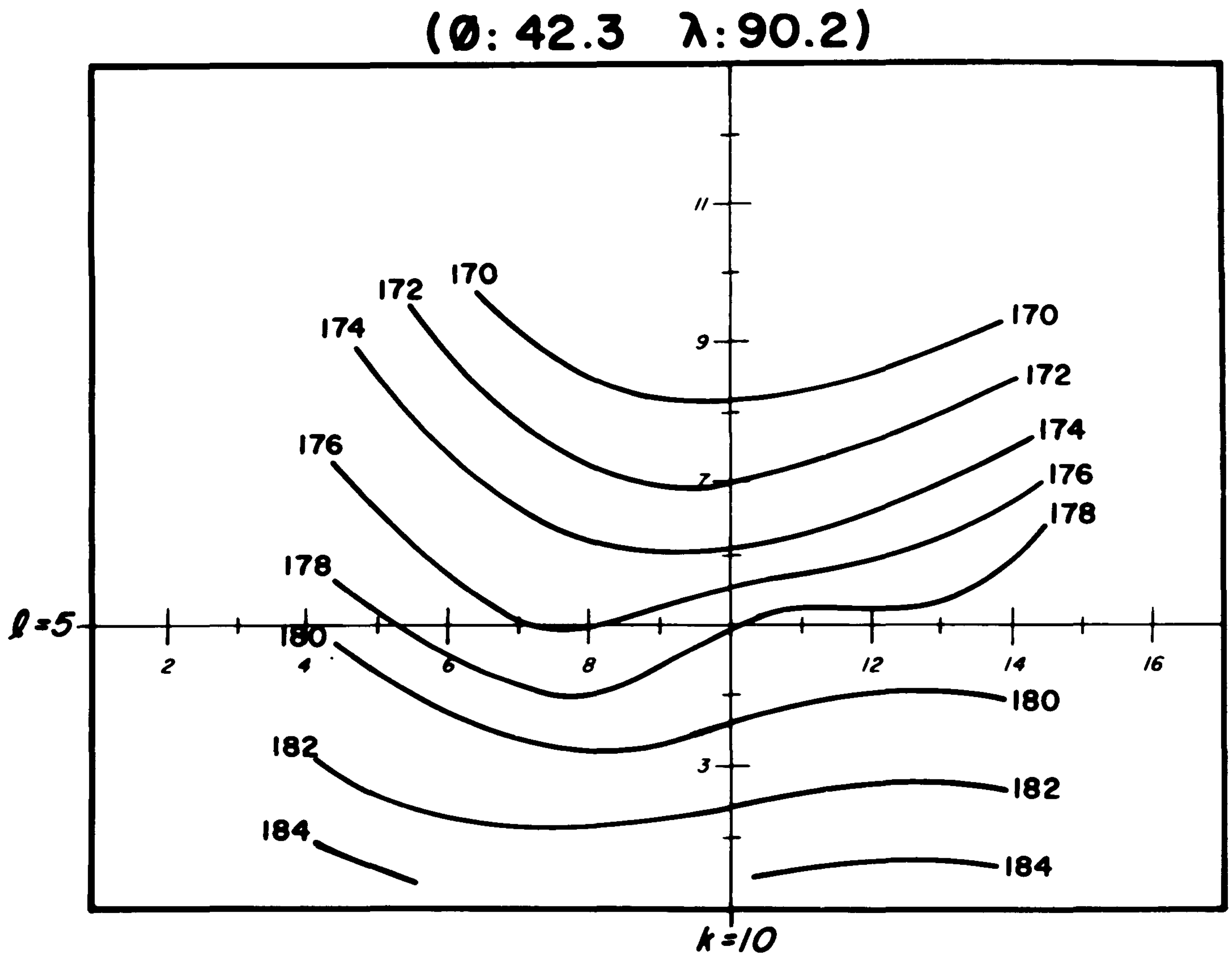

Fig. 4-12. Pooled mean map of 1000–500-mb thickness for winter cyclones in North America, 1955–1959 (dependent sample). Isopachs are labeled in tens of feet.

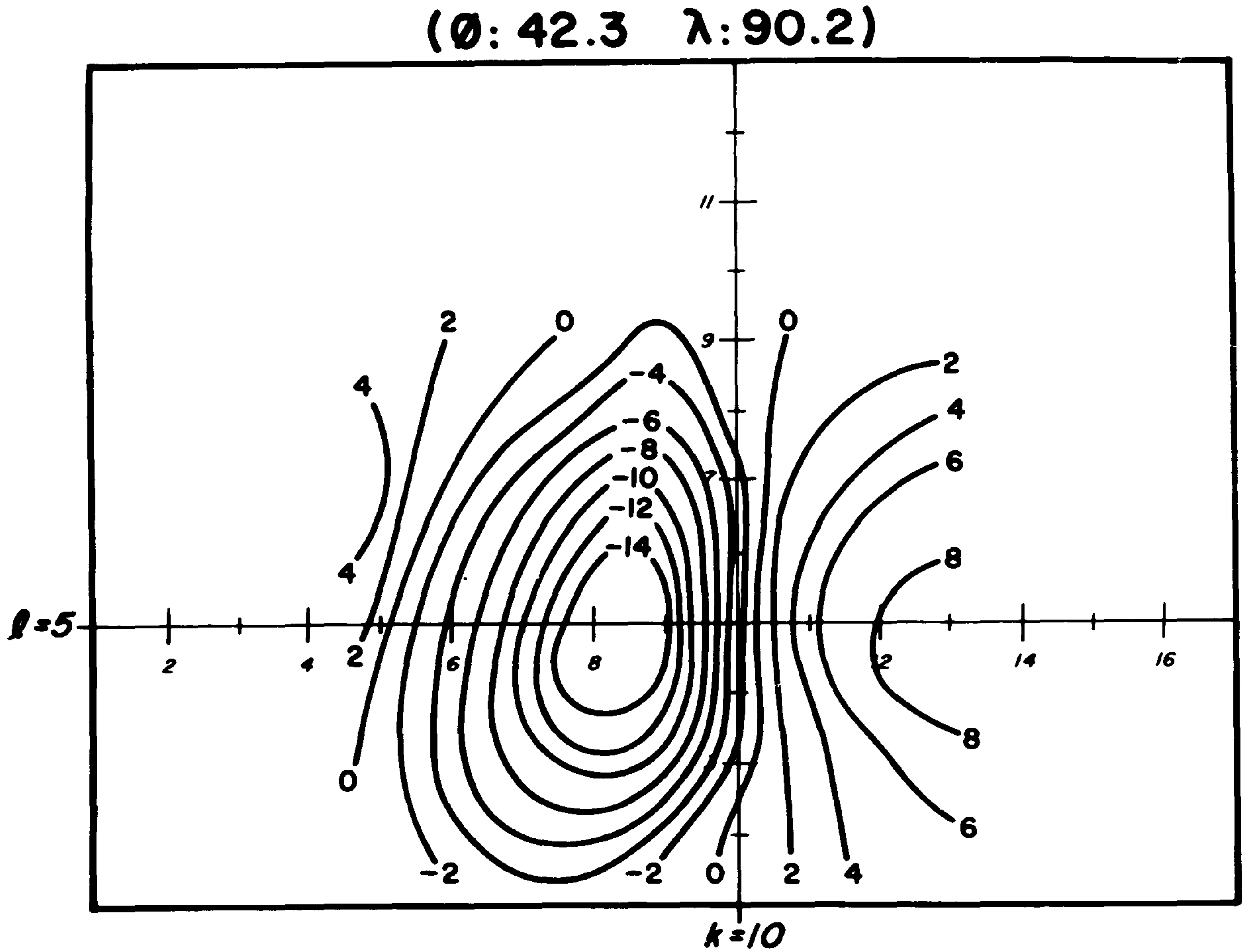

Fig. 4-13. Pooled mean map of 12-hr 1000–500-mb thickness change for winter cyclones in North America, 1955-1959 (dependent sample). Isallopachs are labeled in tens of feet.

cold advection and positive values to warm. The relatively intense cold and warm advections in the northeastern zone result from the strong temperature contrasts associated with the well-developed mature cyclones that typify the northeastern zone.

Figures 4-8 through 4-13 are simply the results of pooling the four zones shown in Figs. 4-2 through 4-7 and are representative of winter cyclones in the entire North American cyclone prediction area.

4.2 Summer Cyclones

Table 4-3 contains the means and standard deviations of the northward and eastward displacements and changes in central pressure of 700 North American summer cyclones (Table 2-1). No stratification by geographical zone was performed. Comparison of Table 4-2 with the "All" portion of Table 4-1 indicates that summer cyclones move more slowly and deepen less than winter cyclones. Also, the standard deviations show that summer cyclones vary less in movement and intensification than winter cyclones.

Figures 4-14 through 4-19 contain the mean pressure, height, and thickness maps for the summer-cyclone sample. A comparison with the mean maps of winter cyclones (Figs. 4-8 through 4-13) shows that summer and winter cyclones have similar patterns but that the summer patterns are naturally less intense.

TABLE 4-3
CHARACTERISTICS OF SUMMER CYCLONES OVER NORTH AMERICA,
1955-1958 (DEPENDENT SAMPLE)

Forecast interval, hr	Observed northward displacement, deg lat		Observed eastward displacement, deg lat		Observed change in central pressure, mb	
	Mean*	Std dev	Mean†	Std dev	Mean‡	Std dev
12	0.84	2.04	-3.30	2.02	-1.08	3.72
24	1.83	3.58	-6.40	3.69	-1.69	5.57

*Negative values represent southward displacement.
†Negative values represent eastward displacement.
‡Negative values represent deepening.

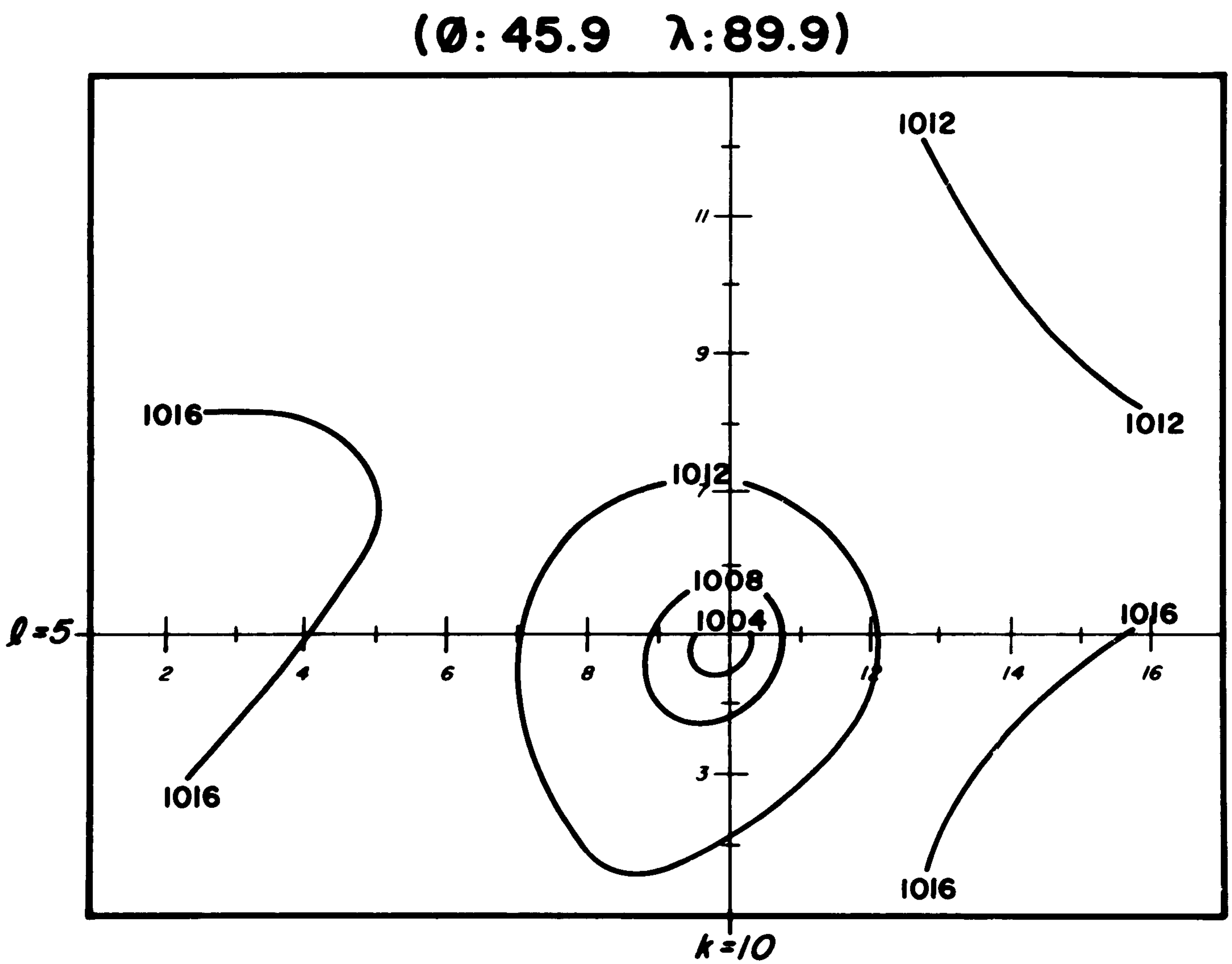

Fig. 4-14. Mean map of sea-level pressure for summer cyclones in North America, 1955-1958 (dependent sample). Isobars are labeled in millibars.

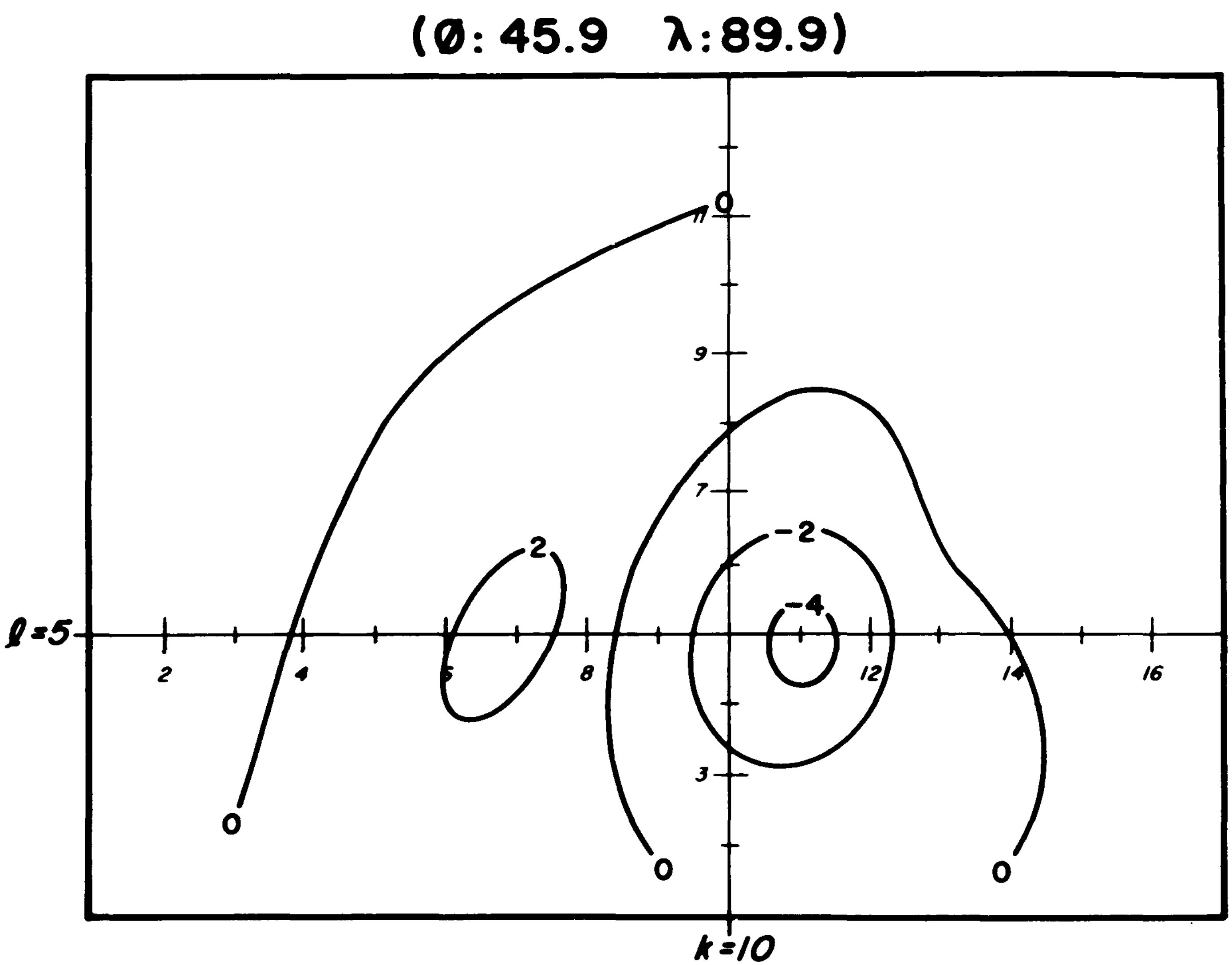

Fig. 4-15. Mean map of 12-hr pressure change for summer cyclones in North America, 1955-1958 (dependent sample). Isallobars are labeled in millibars.

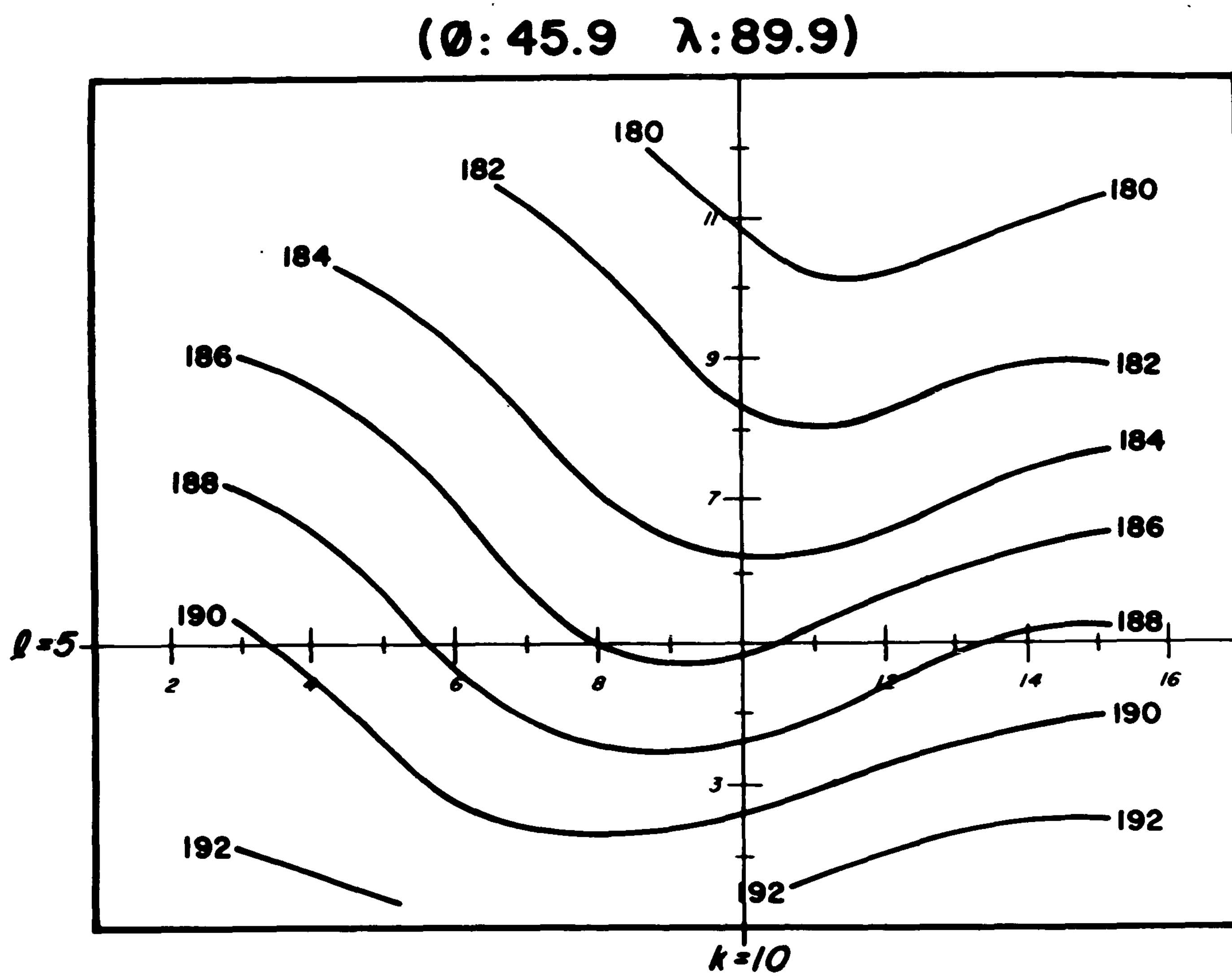

Fig. 4-16. Mean map of 500-mb height for summer cyclones in North America, 1955-1958 (dependent sample). Isohypses are labeled in tens of feet.

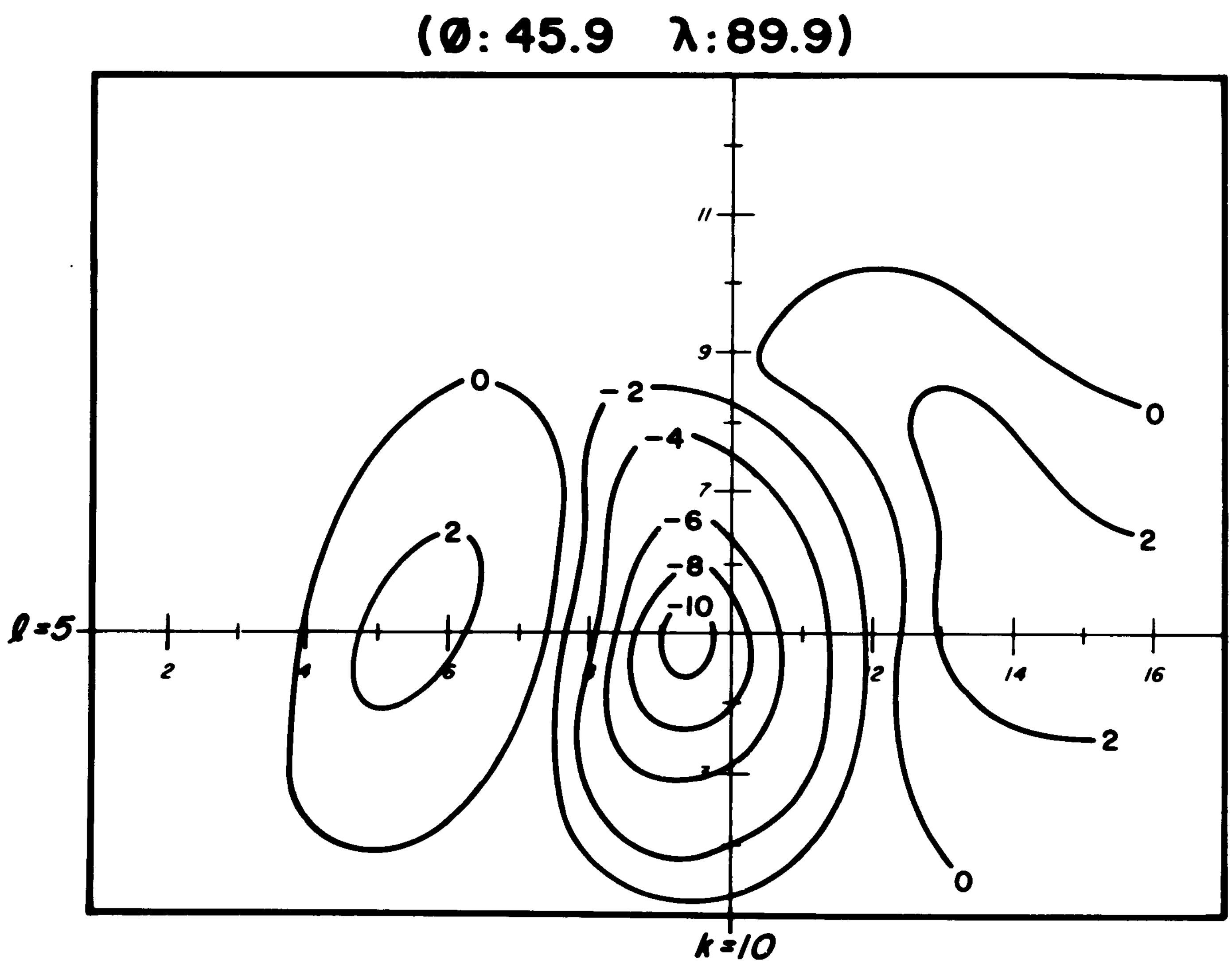

Fig. 4-17. Mean map of 12-hr 500-mb height change for summer cyclones in North America, 1955-1958 (dependent sample). Isallohypses are labeled in tens of feet.

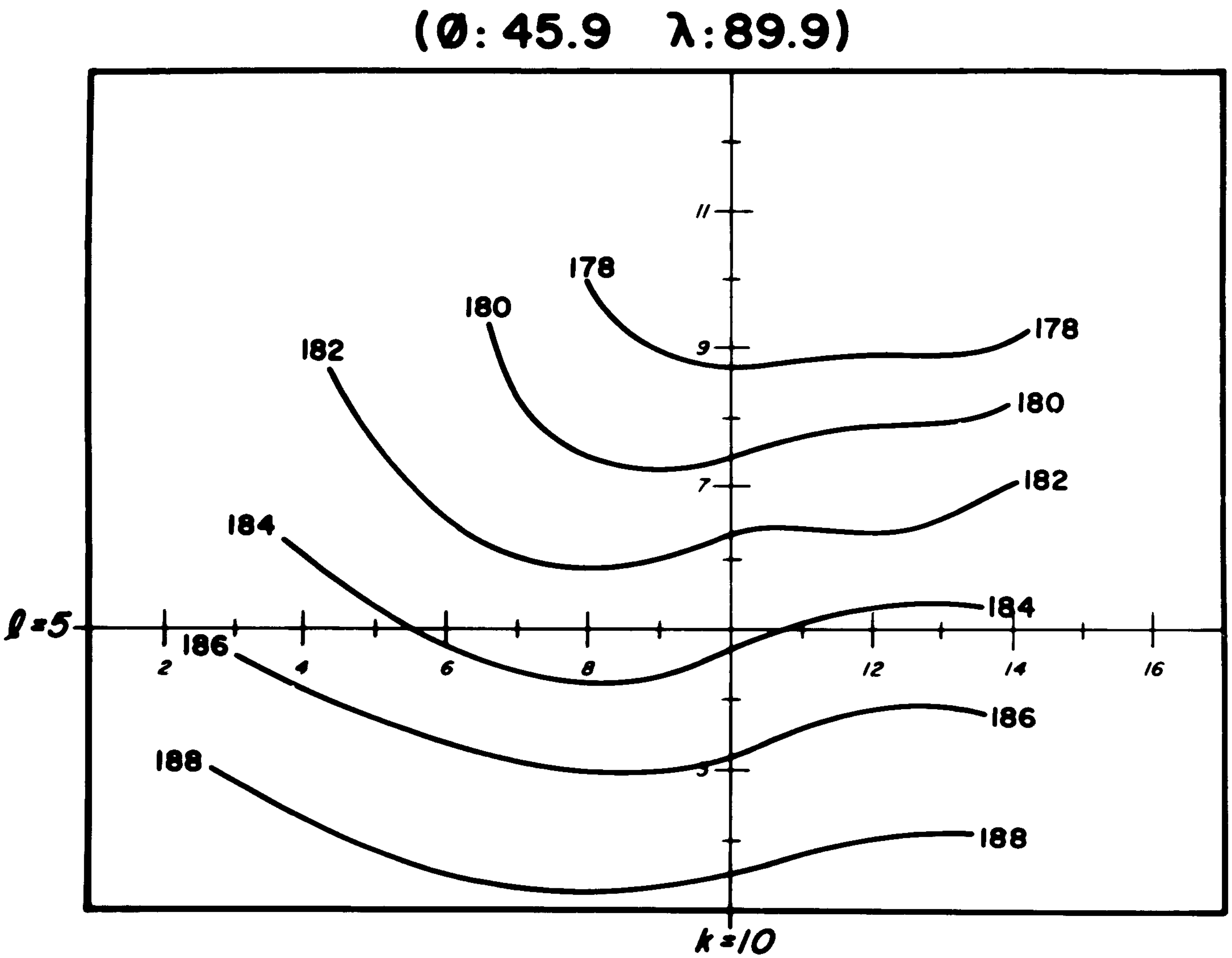

Fig. 4-18. Mean map of 1000–500-mb thickness for summer cyclones in North America, 1955–1958 (dependent sample). Isopachs are labeled in tens of feet.

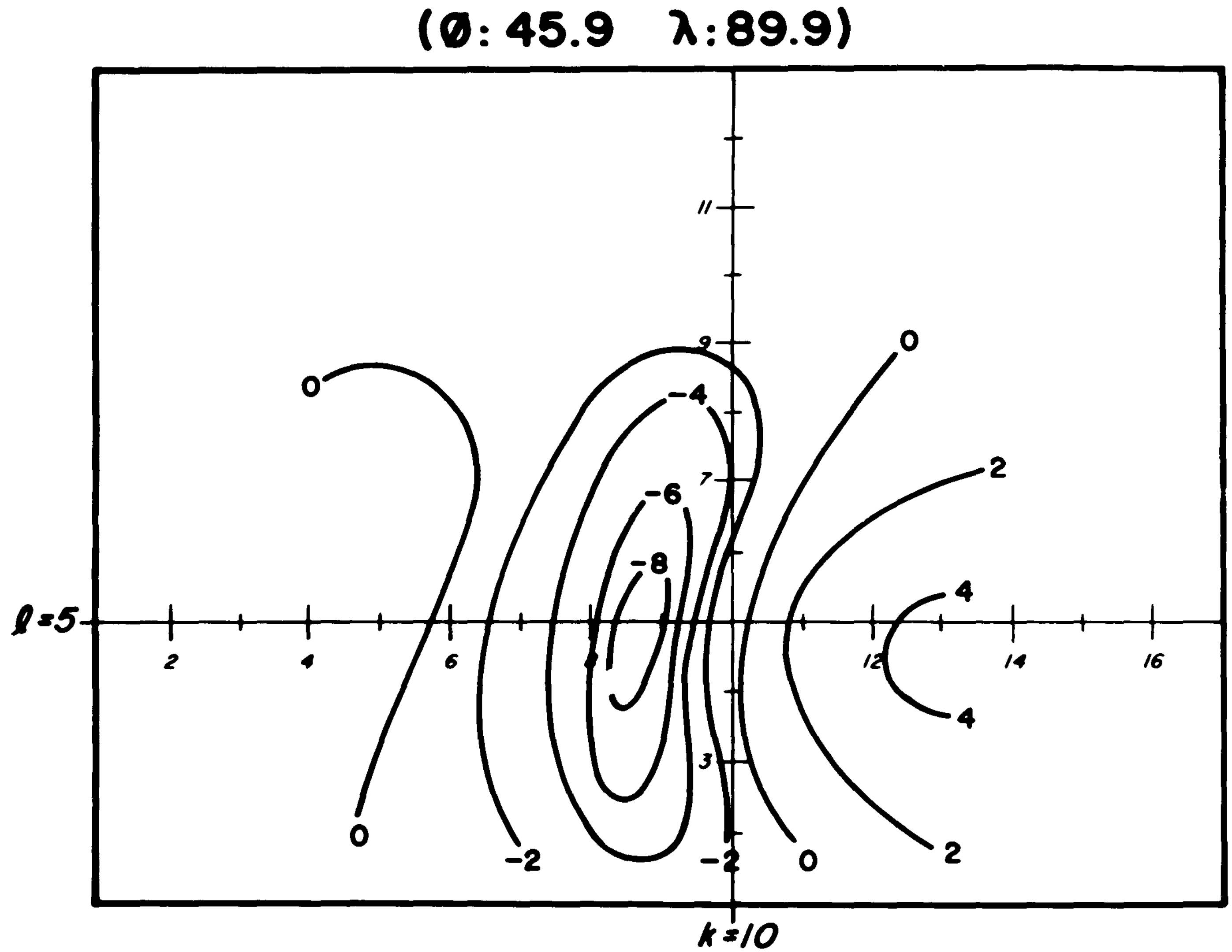

Fig. 4-19. Mean map of 12-hr 1000–500-mb thickness change for summer cyclones in North America, 1955-1958 (dependent sample). Isallopachs are labeled in tens of feet.

5.0 PREDICTION EXPERIMENTS

All the available possible predictors of each predictand must be reduced to a subset to be used in the screening-regression prediction experiments because a single computer run cannot use all 3580 possible predictors (Table 3-2). For each predictand, experimental analysis of various predictor subsets yielded a near-optimum subset, which led in turn to a "base-technique" equation applicable to the entire area of interest and to all cases included in the winter-cyclone developmental sample.* Subsequent analyses, in which the developmental sample was stratified by cyclone position at forecast time and additional possible predictors were screened, were aimed either at improving the results of the base-technique equations or producing equations applicable at observation times other than those included in the developmental sample, i.e., observation times at which only surface data are available.

5.1 Base-technique Prediction Experiments

In the initial experiments, predictors of only types A and B (Table 3-2) were considered. The multitude of possible predictors was reduced by increasing the spacing between gridpoints. (Because meteorological observations are spatially redundant, this hypothetically lost very little of the predictive information contained in the complete set of type A and B predictors.) The remaining number of possible predictors was still more than the maximum (170 to 175) that can be efficiently analyzed by screening regression (as presently programmed for the IBM 7090), so it was decided to conduct two base-technique experiments. Surface (type A) predictors were combined with 700-mb predictors in one experiment and with 500-mb predictors in the other. The combination with 500-mb predictors, as listed in Table 5-1, proved slightly better, so the pertinent equations were defined as the base technique. Results of the base technique on dependent and independent data are given in Section 6.0.

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*Prediction experiments for summer cyclones are discussed in Section 5.6.

TABLE 5-1
POSSIBLE PREDICTORS FOR USE IN BASE-TECHNIQUE AND STRATIFICATION EXPERIMENTS

Type	Symbol*	No. used†
A	ϕ	1
	λ	1
	P	28
	ΔP	26
B	Z	40
	ΔZ	37
	H	18
	ΔH	17

*See Table 3-2 for definitions.
†Total of both types is 168.

TABLE 5-3
POSSIBLE PREDICTORS FOR USE IN EXPERIMENTS INVOLVING SURFACE DATA ONLY

Type	Symbol*	No. used†
A	ϕ	1
	λ	1
	P	84
	ΔP	84

*See Table 3-2 for definitions.
†Total is 170.

TABLE 5-2
POSSIBLE PREDICTORS FOR USE IN EXPERIMENTS INVOLVING DERIVED TERMS

Type	Symbol*	No. used†
A	ϕ	1
	λ	1
	P	12
	ΔP	9
B	Z	7
	ΔZ	12
	H_7	8
	ΔH_7	8
	H	8
	ΔH	7
C	η	11
	$\Delta\eta$	10
	ζ_T	10
	$\Delta\zeta_T$	9
	A_η	10
	A_{H7}	12
	A_H	11
	$A_{\zeta T}$	10
	L	9
	$u_{\bar{7}}, v_{\bar{7}}$	2
	$\Delta u_{\bar{7}}, \Delta v_{\bar{7}}$	2
	u, v, $\lvert V \rvert$	3
	$u_{\bar{7}}', v_{\bar{7}}'$	2

*See Table 3-2 for definitions.
†Total of all three types is 1[illegible].

5.2 Geographic-stratification Experiments

Experiments were performed to determine the usefulness of equations derived from developmental samples stratified according to position of the predictand cyclone at forecast time. The developmental sample was stratified into four zones (see Fig. 2-1 and Table 2-1). The possible predictors considered are listed in Table 5-1. Results and zone-by-zone comparisons with the base-technique equations are presented in Section 6.0.

5.3 Incorporation of Past-history Predictors

The original cyclone-data tabulation includes a 6-hr history of each cyclone's motion (northward and eastward components) and change in central pressure. To test the usefulness of these three possible predictors, they were added to the base technique and the prediction experiment was repeated. The geographic-stratification experiment was repeated for all zones and all predictands because it was suspected that there might be a variation from zone to zone in the accuracy with which the past-history predictors could be estimated–for example, that the position and central pressure of cyclones over the Atlantic Ocean and Gulf of Mexico (in the southeastern zone) might be subject to greater errors than those over land (in, say, the northwestern zone).

The possible predictors considered in these experiments are listed in Table 5-1, with the 3 past-history predictors included.

5.4 Experiments Using Type C Predictors

The third attempt to improve the base-technique prediction equations was to introduce various parameters suggested in the literature as being important predictors of the displacement and change in intensity of cyclones. A description of this class of predictors is contained in Section 3.4.

The required reduction in the number of possible predictors (Table 3-2) was accomplished by computing and mapping correlation coefficients of all possible predictors with each of the predictands. Predictors then selected for

further consideration were those associated with extrema of the mapped correlation fields and are shown in Table 5-2.

The experiment with derived terms was by no means exhaustive, but it does represent an attempt to incorporate professional knowledge into the statistical analysis.

5.5 Development of Prediction Equations from Surface Data Only

The primary objective of developing prediction equations from surface data only was not to improve the results obtained by the base technique but to increase the prediction methods' usefulness.

Application of the base technique is limited. Because 500-mb-height data are received only every 12 hr, regression equations dependent on upper-air data can be applied only at initial times of 0000 and 1200 GCT. One approach to this problem is the use of 500-mb prognoses.* Another approach is to derive regression equations that use only surface data as predictors.

A regression analysis that excludes upper-air data, if successful, would provide a useful means for making a forecast at any observation time for which surface data are available. Accordingly, two experiments were performed. All cases in the developmental sample were analyzed. The possible predictors for these experiments are listed in Table 5-3. One experiment included the past-history predictors; the other did not. Results of these two experiments are presented in Section 6.0 for dependent and independent data.

5.6 Prediction Experiments for Summer Cyclones

Four experiments were conducted to develop prediction equations for the 12- and 24-hr displacement and change in central pressure of summer cyclones.

The first experiment employed the same predictors as the base-technique experiment for winter cyclones described in Section 5.1 (Table 5-1). All

*The authors feel that this approach, not yet attempted, should be attempted.

dependent cases (700) in the entire North American area were analyzed, and the resulting equations were tested on independent cases.

The second experiment included the past-history predictors.

Finally, equations were derived from surface data only, for application when upper-air data are not available. As in the previous pair of experiments, the first prediction experiment did not include the past-history predictors, and the second one did. The possible predictors are those listed in Table 5-3.

Results of these four experiments are summarized in Section 6.0.

6.0 RESULTS

The first series of results discussed (Section 6.1) are those pertaining to winter cyclones. Results obtained from prediction experiments for summer cyclones are presented in Section 6.2. All equations developed can be found in Appendix B.

6.1 Winter Cyclones

The sequence of experiments for winter cyclones was first to establish base-technique prediction equations for the north-south (N) and east-west (E) components of displacement and the change in central pressure (D). Equations were derived for forecast periods of 12, 24, and 36 hr. The entire developmental sample was used to derive these equations, and only parameters routinely available at 0000 and 1200 GCT were considered as possible predictors. Thus, these equations are applicable to all North American cyclones regardless of location, stage of development, or prevailing synoptic pattern. Development of these equations and the results of their application on independent data are given in Section 6.1.1.

Sections 6.1.2 through 6.1.3 are devoted to discussions of the results of experiments aimed at improving the results obtained using the base-technique prediction equations. Improvements were sought by

(a) development of equations derived from developmental samples stratified according to the location of the cyclone of interest at forecast time,

(b) introduction of the displacement and change in central pressure of the cyclone during the 6 hr prior to forecast time as possible predictors, and

(c) introduction of additional derived parameters as possible predictors.

Finally, results of the derivation and testing of equations using only surface parameters are presented in Section 6.1.5.

6.1.1 Results of Using both Surface and Upper-air Predictors

Regression equations were derived for the prediction of the 12-, 24-, and 36-hr displacement and change in central pressure for North American cyclones. The possible predictors are listed in Table 5-1.

The results of the screening-regression analysis are summarized in Tables 6-1 and 6-2. Table 6-1 lists the predictors in the order of their selection by the screening procedure and the percentage of the total variance of the predictand explained by each. Table 6-2 summarizes the initial and residual standard deviations and the percent reductions. The numbers accompanying the predictor symbol in Table 6-1 refer to the (k,ℓ)-predictor locations in the grid system shown in Fig. 3-1.

From Table 6-1, it can be seen that the displacement predictands counted heavily on upper-air information. At least for the first few predictors selected, the sign of the regression coefficient is usually consistent with qualitative reasoning. For example, in each case, the second predictor selected for the prediction of the cyclones' northward component of displacement was a 500-mb height from 3 to 5 grid intervals east of the storm. The regression coefficient associated with this predictor is positive in all three northward-displacement equations: thus, a large-amplitude ridge east of the cyclone would contribute to the prediction of a sizable northward displacement.

It is interesting to note that the longitude, λ, of the cyclone center at forecast time is the first predictor selected for each of the three northward-displacement equations. The sign of the regression coefficient (negative) indicates that this is likely a reflection of the variation of the climatology of storm tracks within the prediction region, i.e., a tendency for a southward component of displacement in the west and for a northward component in the east.

The first two predictors selected for the three eastward-displacement equations follow the same pattern. The first predictor selected is a 500-mb

TABLE 6-1
PREDICTORS SELECTED BY SCREENING REGRESSION*
FOR WINTER CYCLONES OVER NORTH AMERICA

Forecast interval, hr	Order of selection	$\hat{N}$ Predictor	$\hat{N}$ % red	$\hat{I}$ Predictor	$\hat{I}$ % red	$\hat{O}$ Predictor	$\hat{O}$ % red
12	1st	λ	25.3	Z(11,9)	18.4	ΔP(9,5)	13.5
	2nd	Z(13,5)	13.3	Z(9,1)	17.8	λ	6.5
	3rd	Z(9,7)	15.1	ΔP(7,5)	3.6	P(10,5)	5.1
	4th	ΔP(11,7)	2.6	ΔZ(7,3)	2.3	ΔH(9,5)	7.3
	5th	ΔP(9,3)	2.0	ΔZ(11,7)	[illegible]	P(11,5)	5.1
	6th	H(13,3)	0.9	H(9,3)	1.4	H(11,1)	2.1
	7th	P(11,7)	1.0	P(13,7)	[illegible]	Z(9,9)	2.5
	8th	ΔP(9,7)	1.2	P(15,3)	[illegible]	[illegible]	1.3
	9th	P(5,1)	0.8	P(5,7)	0.7	[illegible]	1.8
	10th	P(9,7)	0.8	P(9,3)	0.6	ΔZ(9,3)	0.9
	11th	-	-	P(11,5)	1.2	Z(13,9)	0.8
	12th	-	-	H(9,7)	0.6	-	-
	13th	-	-	H(7,[illegible])	0.9	-	-
	14th	-	-	ΔH(9,5)	0.7	-	-
Total		-	63.0	-	51.8	-	46.8
24	1st	λ	26.0	Z(11,9)	18.4	Z(11,1)	13.3
	2nd	Z(13,5)	14.6	Z(9,1)	20.5	λ	9.1
	3rd	Z(7,7)	12.3	ΔZ(7,3)	[illegible]	ΔZ(9,9)	6.0
	4th	ΔP(11,7)	2.0	P(13,7)	1.[illegible]	[illegible]	[illegible]
	5th	ΔZ(13,3)	1.4	Z(11,3)	2.1	H(9,7)	3.4
	6th	Z(9,7)	1.2	ΔZ(11,7)	1.2	P(10,5)	2.7
	7th	Z(13,7)	2.3	ΔP(7,5)	1.1	ΔZ(9,5)	3.2
	8th	ΔZ(7,7)	1.2	H(7,5)	1.2	P(11,5)	2.3
	9th	Z(13,5)	0.7	Z(11,5)	1.0	ΔP(9,5)	2.0
	10th	ΔP(9,3)	0.7	Z(15,11)	1.0	H(11,5)	1.6
	11th	P(11,9)	0.7	P(13,1)	0.7	P(5,5)	1.3
Total			63.1		52.2		53.6
36	1st	λ	25.1	Z(13,11)	17.7	Z(11,1)	14.4
	2nd	Z(15,5)	14.9	Z(9,1)	12.8	λ	8.7
	3rd	Z(9,7)	12.4	Z(11,9)	7.4	Z(9,9)	6.5
	4th	Z(13,5)	2.8	ΔZ(7,5)	2.4	P(10,5)	8.7
	5th	P(11,7)	1.4	P(13,7)	2.0	ΔZ(9,9)	2.9
	6th	ΔZ(7,7)	1.2	Z(11,3)	2.2	P(13,7)	2.3
	7th	P(15,7)	1.0	Z(15,11)	1.3	ΔZ(9,5)	1.8
	8th	P(9,7)	0.9	H(7,5)	1.0	Z(13,3)	1.3
	9th	Z(15,7)	0.4	P(13,1)	1.5	ΔH(11,5)	1.0
	10th	ΔH(11,5)	0.6	ΔP(13,5)	0.8	P(5,7)	1.1
	11th	-	-	P(3,3)	0.7	ΔP(11,7)	0.7
	12th	-	-	-	-	ΔP(3,3)	0.7
Total			60.7		49.8		50.1

*Including upper-air predictors.

TABLE 6-2
RESULTS OF SCREENING REGRESSION* ON WINTER CYCLONES OVER NORTH AMERICA, 1955-1959 (DEPENDENT SAMPLE)

Forecast interval, hr	No. of predictors			Std dev			Residual std dev			% reduction		
	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$
12	10	14	11	2.79	2.46	5.44	1.70	1.71	3.97	63.0	51.8	46.8
24	11	11	11	4.86	4.47	9.47	2.96	3.09	6.45	63.1	52.2	53.6
36	10	11	12	6.52	6.35	12.76	4.08	4.50	9.01	60.7	49.8	50.1

*Including upper-air predictors.

TABLE 6-3
RMS ERRORS IN TESTS* ON WINTER CYCLONES OVER NORTH AMERICA, 1959-1960 (INDEPENDENT SAMPLE)

Forecast interval, hr	Northward displacement, deg lat		Eastward displacement, deg lat		Vector, deg lat		Change in central pressure, mb	
	Base. tech	Climatol	Base tech	Climatol	Base tech	Climatol	Base tech	Climatol
12	1.62	2.40	1.74	2.43	2.38	4.26	4.28	4.83
24	2.93	4.16	3.09	4.48	4.26	6.88	6.88	8.03
36	4.08	5.49	4.34	6.22	5.96	9.03	9.03	10.50

*Including upper-air predictors.

height north-northeast of the surface cyclone center and the second, a 500-mb height south-southwest of the center. The regression coefficients associated with the two predictors are approximately equal in magnitude and of opposite sign—in effect, a measure of the strength of the eastward "steering" component.

The central pressure's lead predictors, $\Delta P(9,5)$ for 12 hr and $\Delta Z(9,5)$ for 24 hr, correlate 12-hr pressure and height falls to the immediate west of the cyclone with deepening. The first two predictors selected for the 36-hr change-in-central-pressure equations and their coefficients (opposite in sign) indicate a correlation between the strength of the westerlies and deepening.

Table 6-3 contains the results of application of the base-technique equations to 213 cases not used in their development. A comparison of independent-data rms errors with the residual standard deviations of the developmental sample indicates a remarkable degree of stability in the equations.

6.1.2 Results of the Geographic Stratification of the Developmental Sample

Geographic variations in cyclone climatology and in the accuracy with which predictors may be specified suggest that subdividing the developmental sample according to the location of the predictand cyclone and rederiving equations applicable to zones within the forecast area may lead to improved results. Nevertheless, unless very large samples are available, errors in estimating regression coefficients employing subsets of the entire developmental samples may counteract the improvement.

To investigate this possibility for improving the base-technique equations, separate regression equations were derived for cyclones by zone (Fig. 2-1). The predictands and possible predictors were exactly the same as in the previous experiment, which considered all cyclones in the entire forecast area.

The results of the screening-regression analysis are summarized in Tables 6-4 and 6-5. Table 6-4 lists the predictors in the order of their selection by the screening and the percentage of the total variance of the predictand explained by each. Table 6-5 summarizes, by zone, the initial and residual standard deviations

TABLE 6-4
PREDICTORS SELECTED BY SCREENING REGRESSION
FOR WINTER CYCLONES OVER NORTH AMERICA

(a) Northwestern zone

Forecast interval, hr	Order of selection	$\hat{N}$ Predictor	$\hat{N}$ % red	$\hat{E}$ Predictor	$\hat{E}$ % red	$\hat{D}$ Predictor	$\hat{D}$ % red
12	1st	Z(13, 5)	22.5	Z(11, 9)	18.8	ΔP(7, 7)	8.2
	2nd	Z(9, 7)	14.8	Z(11, 1)	12.9	ΔZ(9, 5)	9.1
	3rd	ΔP(11, 7)	5.2	ΔZ(9, 1)	4.9	P(10, 5)	14.0
	4th	λ	5.0	P(11, 5)	3.5	P(11, 5)	8.7
	5th	H(5, 5)	3.1	P(11, 1)	4.4	-	-
	6th	ΔP(5, 5)	3.3	-	-	-	-
	7th	P(11, 3)	3.1	-	-	-	-
Total			57.0		44.5		40.0
24	1st	Z(13, 5)	16.7	Z(11, 9)	25.9	P(10, 5)	10.7
	2nd	Z(9, 7)	19.9	Z(11, 1)	14.8	ΔZ(9, 5)	19.1
	3rd	λ	10.7	ΔZ(9, 3)	4.1	P(11, 5)	5.3
	4th	ΔZ(5, 5)	4.5	P(11, 5)	3.7	ΔZ(9, 7)	4.1
	5th	-	-	P(13, 1)	3.3	-	-
Total			51.8		51.8		39.2
36	1st	H(13, 5)	12.8	Z(11, 9)	26.9	P(10, 5)	14.1
	2nd	H(7, 7)	14.1	Z(11, 1)	15.7	ΔZ(9, 5)	12.5
	3rd	λ	6.9	ΔZ(9, 3)	2.9	Z(15, 1)	6.0
	4th	Z(13, 3)	3.9	P(11, 5)	3.1	ΔZ(9, 7)	5.1
	5th	Z(9, 7)	3.5	P(13, 1)	3.6	-	-
	6th	Z(13, 5)	3.9	-	-	-	-
Total			45.1		52.2		37.7

(b) Northeastern zone

Forecast interval, hr	Order of selection	$\hat{N}$		$\hat{E}$		[illegible]	
		Predictor	% red	Predictor	% red	Predictor	% red
12	1st	Z(15, 5)	33.3	Z(11, 9)	[illegible]	Z([illegible], 3	[illegible]
	2nd	Z(7, 7)	14.3	[illegible]	11.[illegible]	[illegible]	[illegible]
	3rd	Z(13, 7)	8.6	Z(11, 7)	[illegible]	[illegible]	[illegible]
	4th	Z(9, 7)	4.0	F(1[illegible], 5)	2.6	[illegible]	[illegible]
	5th	-	-	[illegible]	[illegible]	[illegible]	[illegible]
	6th	-	-	Z(11,11)	[illegible]	[illegible]	[illegible]
	7th	-	-	-	-	[illegible]	[illegible]
Total			[illegible]		61.3		[illegible]
24	1st	Z(15, 5)	[illegible]	Z(11, 9)	[illegible]	[illegible]	[illegible]
	2nd	Z(7, 7)	12.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	3rd	Z(15, 7)	[illegible]	-	-	[illegible]	[illegible]
	4th	-	-	-	-	[illegible]	[illegible]
	5th	-	-	-	-	[illegible]	[illegible]
	6th	-	-	-	-	[illegible]	[illegible]
	7th	-	-	-	-	[illegible]	[illegible]
	8th	-	-	-	-	[illegible]	[illegible]
Total			56.9		[illegible]		[illegible]
36	1st	Z(15, 5)	36.1	Z(13, [illegible])	[illegible]	[illegible]	[illegible]
	2nd	Z(9, 7)	14.1	F(13, 1)	[illegible]	[illegible]	11.[illegible]
	3rd	Z(15, 7)	10.4	[illegible]	3.1	[illegible]	[illegible]
	4th	ΔH(9, 1)	3.5	H(5, 9)	[illegible]	[illegible]	[illegible]
	5th	-	-	-	-	[illegible]	[illegible]
	6th	-	-	-	-	[illegible]	[illegible]
Total			64.1		[illegible]		[illegible]

(c) Southwestern zone

Forecast interval, hr	Order of selection	$\hat{N}$ Predictor	$\hat{N}$ % red	$\hat{E}$ Predictor	$\hat{E}$ % red	$\hat{D}$ Predictor	$\hat{D}$ % red
12	1st	Z(13, 3)	30.2	Z(9, 9)	12.7	ΔP(9, 7)	16.1
	2nd	λ	9.1	ΔP(7, 5)	9.3	P(5, 5)	6.4
	3rd	Z(7, 7)	6.4	H(7, 5)	8.5	-	-
	4th	Z(15, 7)	3.0	-	-	-	-
	5th	H(13, 3)	2.3	-	-	-	-
	6th	P(11, 5)	3.8	-	-	-	-
	7th	ΔP(9, 7)	2.8	-	-	-	-
	8th	P(3, 9)	2.9	-	-	-	-
	9th	P(11, 3)	1.6	-	-	-	-
	10th	P(13, 1)	1.9	-	-	-	-
Total			64.0		30.5		22.5
24	1st	Z(13, 3)	34.6	Z(9,11)	15.0	ΔP(9, 7)	7.5
	2nd	λ	10.5	ΔP(7, 5)	8.2	Z(11, 1)	5.2
	3rd	Z(9, 7)	9.7	H(7, 5)	4.8	H(9, 7)	5.1
	4th	H(13, 9)	5.2	Z(11, 7)	3.5	P(10, 5)	4.3
	5th	P(15, 3)	2.0	ΔP(13, 5)	4.4	P(11, 7)	6.2
	6th	P(3, 3)	2.0	Z(13, 3)	4.5	ΔH(7, 3)	3.5
	7th	ΔP(9, 7)	1.4	-	-	-	-
	8th	Z(15, 5)	1.5	-	-	-	-
	9th	P(11, 5)	0.9	-	-	-	-
	10th	P(13, 3)	1.7	-	-	-	-
Total			69.5		40.4		31.8
36	1st	Z(15, 3)	29.4	Z(9,11)	15.9	Z(11, 1)	11.3
	2nd	λ	14.0	ΔP(7, 5)	5.6	Z(9,11)	9.1
	3rd	Z(7, 7)	9.9	H(7, 5)	4.7	P(10, 5)	4.5
	4th	P(11, 9)	5.4	-	-	-	-
Total			58.7		26.2		24.9

(d) Southeastern zone

Forecast interval, hr	Order of selection	$\hat{N}$ Predictor	$\hat{N}$ % red	$\hat{E}$ Predictor	$\hat{E}$ % red	$\hat{D}$ Predictor	$\hat{D}$ % red
12	1st	P(9, 9)	18.9	Z(11, 9)	31.1	ΔP(9, 3)	22.7
	2nd	Z(13, 5)	14.6	Z(7, 3)	20.6	ΔZ(9, 5)	9.1
	3rd	Z(7, 7)	11.6	ΔP(7, 3)	5.2	Z(11, 3)	4.5
	4th	ΔP(9, 5)	5.8	P(13, 7)	2.2	H(7, 9)	3.6
	5th	Z(13, 7)	2.7	-	-	ΔP(7, 5)	3.1
Total			53.6		59.1		43.0
24	1st	P(9, 9)	17.4	Z(13,11)	29.4	ΔP(9, 3)	24.4
	2nd	Z(15, 5)	14.7	Z(9, 1)	16.0	Z(11, 1)	8.8
	3rd	Z(7, 7)	14.2	P(13, 7)	9.8	H(7, 9)	7.4
	4th	ΔP(9, 5)	6.1	Z(11, 9)	3.5	ΔZ(9, 9)	4.6
	5th	Z(15, 7)	2.2	Z(7, 5)	5.3	P(5, 5)	3.1
	6th	H(7, 9)	2.0	Z(15,11)	1.6	P(13, 1)	1.8
	7th	-	-	ΔZ(5, 3)	1.7	ΔZ(11, 7)	0.9
	8th	-	-	-	-	ΔP(9, 5)	0.8
	9th	-	-	-	-	P(10, 5)	1.3
	10th	-	-	-	-	P(11, 7)	2.4
Total			56.6		67.3		55.4
36	1st	Z(7, 9)	13.7	Z(9, 1)	29.0	ΔP(9, 3)	17.1
	2nd	Z(15, 7)	28.1	Z(13, 9)	20.5	Z(9, 1)	11.0
	3rd	ΔP(9, 5)	4.5	Z(7, 5)	4.3	ΔH(9, 9)	9.0
	4th	P(11, 9)	3.7	P(11, 7)	4.2	Z(9, 9)	4.4
	5th	ΔZ(7, 5)	3.0	Z(13, 1)	2.8	P(10, 5)	2.4
	6th	-	-	Z(3, 1)	1.8	-	-
Total			53.0		62.6		43.9

TABLE 6-6
RMS ERRORS IN TESTS ON WINTER CYCLONES,*
1959-1960 (INDEPENDENT SAMPLE)

Zone	n	Forecast interval, hr	Northward displacement, deg lat			Eastward displacement, deg lat			Change in central pressure, mb		
			Unstrat base tech	Strat	Climatol	Unstrat base tech	Strat	Climatol	Unstrat base tech	Strat	Climatol
NW	43	12	1.70	1.69	2.23	1.22	1.31	2.52	4.06	4.68	4.39
		24	3.23	3.11	4.06	2.29	2.05	4.74	7.05	7.34	7.37
		36	4.15	3.52†	5.67	3.21	3.57	6.64	10.42	9.54	10.46
NE	34	12	1.83	1.76	2.72	1.49	2.08	2.87	4.36	4.09	4.20
		24	3.52	3.14	4.78	2.69	3.92	5.46	6.38	7.01	7.96
		36	4.63	4.71	5.82	4.09	5.96	7.71	8.99	9.57	11.25
SW	69	12	1.73	1.93	2.59	1.90	2.01	2.08	4.07	4.54	4.60
		24	3.07	3.14	4.39	3.52	3.64	3.76	6.99	6.95	7.35
		36	4.20	4.90	5.81	4.94	4.97	4.81	8.90	10.07	8.52
SE	67	12	1.31	1.34	2.07	1.95	2.01	2.24	4.58	4.98	6.12
		24	2.16	2.26	3.42	3.26	3.03	3.95	6.90	6.83	9.44
		36	3.52	3.60	4.65	4.42	4.82	5.73	8.20	9.91	11.75

*Including upper-air predictors.
†Significant at the 5% level.

TABLE 6-6
RMS ERRORS IN TESTS ON WINTER CYCLONES,*
1959-1960 (INDEPENDENT SAMPLE)

Zone	n	Forecast interval, hr	Northward displacement, deg lat			Eastward displacement, deg lat			Change in central pressure, mb		
			Unstrat base tech	Strat	Climatol	Unstrat base tech	Strat	Climatol	Unstrat base tech	Strat	Climatol
NW	43	12	1.70	1.69	2.23	1.22	1.31	2.52	4.06	4.68	4.39
		24	3.23	3.11	4.06	2.29	2.05	4.74	7.05	7.34	7.37
		36	4.15	3.52†	5.67	3.21	3.57	6.64	10.42	9.54	10.46
NE	34	12	1.83	1.76	2.72	1.49	2.08	2.87	4.36	4.09	4.20
		24	3.52	3.14	4.78	2.69	3.92	5.46	6.38	7.01	7.96
		36	4.63	4.71	5.82	4.09	5.96	7.71	8.99	9.57	11.25
SW	69	12	1.73	1.93	2.59	1.90	2.01	2.08	4.07	4.54	4.60
		24	3.07	3.14	4.39	3.52	3.64	3.76	6.99	6.95	7.35
		36	4.20	4.90	5.81	4.94	4.97	4.81	8.90	10.07	8.52
SE	67	12	1.31	1.34	2.07	1.95	2.01	2.24	4.58	4.98	6.12
		24	2.16	2.26	3.42	3.26	3.03	3.95	6.90	6.83	9.44
		36	3.58	3.60	4.65	4.42	4.82	5.73	8.20	9.91	11.75

*Including upper-air predictors.
†Significant at the 5% level.

and the percent reductions. The numbers accompanying the predictor symbols in Table 6-4 refer to the (k,ℓ)-predictor locations in the grid system shown in Fig. 3-1.

Table 6-6 contains the results of the application of the equations, by zone, to the independent sample of 213 cases. Also listed in Table 6-6 are the rms errors, by zone, resulting from the application of the base-technique equations.

Although 11 of the 36 stratified equations resulted in lower rms errors than those associated with the same forecasts using the base-technique equations, only the northwestern-zone equation for the 36-hr northward displacement was significantly better (at less than the 5% level) than the base-technique equation. The significance test employed is Student's t-test for paired comparisons, described by Wadsworth and Bryan [15].

Accordingly, the base technique was redefined for predictions of the 36-hr northward displacement in the northwestern zone.

6.1.3 Results of Incorporating Past History as Possible Predictors

The next experiments were carried out to see if improvements could be realized by using the past history as predictors. Specifically, three new possible predictors were considered. They are the north-south and east-west components of a cyclone's displacement during the 6-hr period just prior to forecast time and the change in central pressure of the cyclone during the same time. The sole difference between these experiments and the previous series was the consideration of the three additional possible predictors. Both the stratified and unstratified samples were analyzed because of the possibility that errors in estimating the past track and change in central pressure would vary from zone to zone.

The results of the screening-regression analysis are summarized in Tables 6-7 and 6-8. Table 6-7 lists the selected predictors, in order of selection by the screening procedure, and the percentage of the total variance explained by each. Table 6-8 summarizes the initial and residual standard deviations and the percent reductions.

TABLE 6-[illegible]
PREDICTORS SELECTED BY SCREENING REGRESSION
FOR WINTER CYCLONES OVER NORTH AMERICA*
(PAST HISTORY INCLUDED)

(a) Northwestern zone

Forecast interval, hr	Order of selection	$\hat{N}$ Predictor	$\hat{N}$ % red	$\hat{E}$ Predictor	$\hat{E}$ % red	$\hat{D}$ Predictor	$\hat{D}$ % red
12	1st	ΔΦ	43.4	Δλ	22.1	ΔZ(9, 7)	9.2
	2nd	ΔH(13, 5)	4.9	Z(11, 9)	10.0	P(10, 5)	10.8
	3rd	Z(13, 5)	2.2	Z(13, 1)	8.2	ΔZ(9, 5)	9.0
	4th	Z(9, 7)	4.1	-	-	P(11, 5)	11.3
	5th	λ	3.5	-	-	-	-
Total			58.1		40.3		40.3
24	1st	ΔΦ	26.3	Z(11, 9)	24.4	ΔZ(9, 7)	12.2
	2nd	ΔH(13, 5)	7.9	Z(11, 1)	15.9	P(10, 5)	15.9
	3rd	λ	4.7	∇Z(9,11)	3.7	ΔZ(9, 5)	8.4
	4th	Z(15, 3)	5.5	P(13, 7)	2.7	P(11, 5)	6.3
	5th	∇Z(13, 9)	3.4	ΔZ(9, 3)	3.7	ΔP_c	4.8
	6th	Z(9, 7)	3.2	-	-	-	-
	7th	Z(13, 5)	4.9	-	-	-	-
Total			55.9		50.4		47.6
36	1st	H(13, 5)	17.3	Z(11, 9)	25.0	P(10, 5)	12.7
	2nd	H(7, 7)	14.7	Z(11, 1)	16.5	ΔZ(9, 7)	13.2
	3rd	-	-	-	-	Z(13, 1)	6.0
Total			32.0		41.5		31.9

*Including upper-air predictors.

(b) Northeastern zone

Forecast interval, hr	Order of selection	$\hat{N}$ Predictor	$\hat{N}$ % red	$\hat{E}$ Predictor	$\hat{E}$ % red	$\hat{D}$ Predictor	$\hat{D}$ % red
12	1st	Δϕ	50.0	Z(11, 9)	40.1	ΔZ(9, 3)	14.1
	2nd	Z(15, 7)	9.0	ΔP(7, 5)	9.8	ΔZ(9, 9)	9.4
	3rd	Z(9, 7)	5.4	ΔZ(11, 7)	4.9	P(10, 5)	6.5
	4th	-	-	-	-	P(9, 7)	6.3
Total			64.4		54.8		36.3
24	1st	Δϕ	40.2	Z(11, 9)	45.9	Z(9, 7)	13.5
	2nd	Z(15, 7)	13.0	Z(11, 1)	7.0	ΔZ(5, 5)	10.5
	3rd	Z(9, 7)	10.5	Z(13, 7)	3.5	ΔZ(9, 9)	9.8
	4th	-	-	ΔZ(7, 5)	3.4	P(10, 5)	5.9
	5th	-	-	H(7, 9)	2.2	-	-
	6th	-	-	P(15, 3)	3.1	-	-
Total			63.7		65.1		39.7
36	1st	Z(15, 5)	54.7	Z(13, 9)	43.8	H(9, 7)	19.3
	2nd	Z(9, 7)	14.3	P(13, 1)	7.2	ΔZ(5, 5)	10.7
	3rd	Z(15, 7)	12.0	-	-	ΔZ(9, 9)	9.1
	4th	-	-	-	-	P(15, 9)	5.3
	5th	-	-	-	-	Z(13, 3)	4.6
	6th	-	-	-	-	P(10, 5)	5.3
	7th	-	-	-	-	Z(9, 3)	4.2
	8th	-	-	-	-	P(11, 7)	3.5
	9th	-	-	-	-	ΔP(9, 5)	3.6
Total			61.0		51.0		65.6

(c) Southwestern zone

Forecast interval, hr	Order of selection	$\hat{N}$ Predictor	$\hat{N}$ % red	$\hat{E}$ Predictor	$\hat{E}$ % red	$\hat{D}$ Predictor	$\hat{D}$ % red
12	1st	Δφ	41.2	Δλ	29.3	ΔP(9, 7)	13.5
	2nd	Z(15, 5)	11.5	Z(11, 7)	4.3	P(5, 5)	6.6
	3rd	λ	5.9	Z(7, 5)	5.1	-	-
	4th	Δλ	3.1	ΔP(7, 3)	5.8	-	-
Total			61.7		44.5		20.1
24	1st	Z(13, 3)	32.7	Δλ	26.0	Δφ	9.2
	2nd	P(11, 7)	11.7	Z(11,11)	7.6	Z(9, 11)	6.5
	3rd	Δφ	9.9	ΔZ(7, 3)	4.8	P(10, 5)	7.5
	4th	λ	5.0	ΔP(11, 9)	3.9	ΔZ(9, 5)	5.1
	5th	Z(9, 7)	4.4	-	-	P(11, 5)	3.5
	6th	-	-	-	-	ΔH(11, 5)	3.9
Total			63.7		42.3		35.7
36	1st	Z(15, 5)	28.4	Δλ	22.3	Z(9,11)	11.8
	2nd	Z(7, 9)	15.5	Z(11,11)	10.2	Z(11, 3)	11.5
	3rd	λ	8.3	ΔZ(7, 3)	4.1	P(10, 5)	3.3
	4th	P(11, 5)	3.5	ΔP(11, 9)	3.7	P(11, 5)	5.0
	5th	P(13, 3)	3.4	ΔH(13, 3)	2.2	-	-
	6th	Z(3, 9)	3.1	Z(15, 1)	2.0	-	-
	7th	-	-	ΔZ(11, 7)	2.2	-	-
	8th	-	-	Z(13, 7)	3.1	-	-
	9th	-	-	P(11, 1)	2.6	-	-
	10th	-	-	φ	2.4	-	-
	11th	-	-	Z(5,11)	3.0	-	-
Total			62.2		57.8		31.6

(d) Southeastern zone

Forecast interval, hr	Order of selection	$\hat{N}$ Predictor	$\hat{N}$ % red	$\hat{E}$ Predictor	$\hat{E}$ % red	$\hat{D}$ Predictor	$\hat{D}$ % red
12	1st	$\Delta\Phi$	40.1	$\Delta\lambda$	42.1	$\Delta P(9, 3)$	22.3
	2nd	ΔP_c	6.3	$Z(11, 9)$	9.7	$\Delta Z(9, 5)$	10.1
	3rd	$P(9, 9)$	5.0	$Z(7, 3)$	10.5	$Z(11, 3)$	4.8
	4th	$Z(15, 5)$	4.1	$\Delta P(7, 3)$	2.7	$H(7, 9)$	4.1
	5th	$H(5, 7)$	4.4	$\Delta Z(11, 7)$	2.0	$\Delta P(7, 5)$	3.2
	6th	$\Delta P(11, 7)$	2.4	-	-	$\Delta H(9, 9)$	2.0
	7th	-	-	-	-	$P(13, 5)$	1.6
	8th	-	-	-	-	$P(5, 5)$	1.9
	9th	-	-	-	-	$\Delta\Phi$	1.1
	10th	-	-	-	-	$P(10, 5)$	1.1
	11th	-	-	-	-	$P(11, 5)$	2.2
Total			62.3		67.0		54.4
24	1st	$\Delta\Phi$	30.2	$\Delta\lambda$	38.3	$\Delta P(9, 3)$	26.3
	2nd	$Z(9, 9)$	8.6	$Z(13, 11)$	10.6	$Z(11, 1)$	8.2
	3rd	$H(13, 7)$	14.6	$Z(7, 3)$	8.8	$H(7, 9)$	6.7
	4th	$\Delta Z(7, 5)$	3.0	$P(13, 7)$	5.9	$\Delta H(9, 9)$	4.2
	5th	-	-	$Z(11, 9)$	2.6	$P(5, 5)$	2.2
	6th	-	-	$Z(15, 1)$	2.2	$\Delta P(11, 9)$	1.9
	7th	-	-	$\Delta Z(11, 7)$	1.7	$P(13, 1)$	1.2
	8th	-	-	$Z(3, 1)$	1.7	$\Delta P(9, 5)$	1.2
	9th	-	-	-	-	$P(10, 5)$	1.2
	10th	-	-	-	-	$P(11, 5)$	3.2
Total			56.4		71.8		56.3
36	1st	$Z(7, 9)$	17.3	$\Delta\lambda$	33.2	$\Delta P(9, 3)$	20.1
	2nd	$Z(15, 7)$	24.5	$Z(9, 1)$	12.6	$Z(9, 1)$	10.5
	3rd	$\Delta P(10, 5)$	5.9	$Z(13, 9)$	9.8	$\Delta H(9, 9)$	8.6
	4th	$\Delta Z(7, 5)$	4.2	$Z(7, 5)$	4.3	$Z(9, 9)$	3.9
	5th	$P(11, 9)$	4.1	$Z(15, 1)$	3.1	$P(10, 5)$	2.7
	6th	-	-	$P(11, 7)$	2.3	$H(13, 5)$	2.2
	7th	-	-	$Z(3, 1)$	2.2	$\Delta Z(3, 7)$	1.3
	8th	-	-	-	-	$\Delta P(9, 5)$	1.2
	9th	-	-	-	-	$P(13, 7)$	2.1
Total			56.0		67.5		52.6

(e) All zones

Forecast interval, hr	Order of selection	$\hat{N}$		E		θ	
		Predictor	% red	Predictor	% red	Predictor	% red
12	1st	ΔΦ	51.4	Δλ	35.0	ΔP(9, 5)	13.4
	2nd	Z(15, 5)	4.9	Z(11, 9)	5.1	λ	6.9
	3rd	Z(9, 7)	4.4	Z(9, 1)	7.3	Z(11, 3)	5.2
	4th	H(11, 7)	2.3	ΔZ(7, 3)	2.4	H(9, 5)	4.8
	5th	P(13, 3)	1.6	ΔZ(11, 7)	2.0	ΔZ(9, 9)	3.3
	6th	λ	1.3	P(13, 5)	1.5	ΔZ(9, 3)	1.8
	7th	-	-	P(15, 3)	1.2	P(10, 5)	3.5
	8th	-	-	Z(9, 3)	[illegible]	P(11, [illegible])	[illegible]
	9th	-	-	ΔZ(7, [illegible])	[illegible]	Φ	1.0
	10th	-	-	-	-	H(7, 1)	1.4
Total			65.9		56.3		49.0
24	1st	ΔΦ	39.7	Δλ	30.5	λ	13.4
	2nd	Z(15, 5)	7.8	Z(13,11)	6.8	Z(11, 3)	9.1
	3rd	Z(9, 7)	8.9	Z(9, 1)	5.3	Z(9, 7)	7.3
	4th	H(11, 7)	2.6	Z(11, 9)	4.3	ΔZ(9, 9)	4.6
	5th	λ	1.8	ΔZ(7, 5)	2.6	P(10, 5)	3.8
	6th	P(13, 3)	1.2	P(15, 7)	2.4	ΔP_c	4.0
	7th	ΔZ(7, 7)	0.7	Z(11, 3)	1.3	P(11, 5)	4.7
	8th	-	-	ΔZ(11, [illegible])	1.2	ΔZ(10, 5)	2.6
	9th	-	-	H(13, [illegible])	[illegible]	P([illegible])	1.4
	10th	-	-	ΔP(9, 9)	0.8	P(9, 3)	1.5
	11th	-	-	-	-	ΔΦ	1.1
Total			62.7		56.1		55.7
36	1st	ΔΦ	30.5	Δλ	26.1	Z(11, 1)	13.1
	2nd	Z(15, 3)	9.6	Z(13,11)	8.5	Z(9, 9)	9.7
	3rd	Z(9, 9)	7.6	Z(9, 1)	6.9	λ	6.9
	4th	H(13, 7)	6.6	P(13, 7)	2.9	P(10, 5)	8.6
	5th	λ	2.0	P(13, 1)	1.7	P(11, 7)	3.1
	6th	Z(9, 7)	0.8	H(7, 5)	2.6	ΔP(10, 5)	2.9
	7th	P(15, 7)	1.2	Z(5, 1)	1.3	H(13, 3)	2.0
	8th	ΔH(7, 7)	1.1	Z(11, 9)	1.0	P(5, 7)	1.6
	9th	-	-	ΔZ(7, 5)	1.3	ΔZ(9, 9)	1.4
	10th	-	-	Z(15,11)	1.2	H(9, 7)	1.1
	11th	-	-	Z(15, 1)	0.8	P(9, 3)	1.0
	12th	-	-	λ	1.1	-	-
	13th	-	-	P(3, 3)	0.6	-	-
	14th	-	-	ΔZ(11, 7)	0.5	-	-
	15th	-	-	ΔP(9, 9)	0.7	-	-
	16th	-	-	P(7, 9)	0.6	-	-
	17th	-	-	P(9, 7)	1.0	-	-
Total			59.4		58.8		51.4

TABLE 6-8
RESULTS OF SCREENING REGRESSION* ON WINTER CYCLONES OVER NORTH AMERICA, INCLUDING PAST HISTORY, 1955-1959 (DEPENDENT SAMPLE)

Zone	Forecast interval, hr	No. of predictors			Std dev			Residual std dev			% reduction		
		$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$
NW	12	5	3	4	2.46	2.07	4.73	1.59	1.60	3.65	58.1	40.3	40.3
	24	7	5	5	4.30	3.54	7.37	2.86	2.49	5.33	55.9	50.4	47.6
	36	2	2	3	5.62	4.90	9.04	4.64	3.75	7.46	32.0	41.5	31.9
NE	12	3	3	4	2.58	2.36	4.66	1.54	1.59	3.72	64.4	54.8	36.3
	24	3	6	4	4.44	4.60	8.69	2.67	2.72	6.75	63.7	65.1	39.7
	36	3	2	9	5.70	6.67	12.68	3.56	4.67	7.43	61.0	51.0	65.6
SW	12	4	4	2	2.74	2.36	4.57	1.70	1.76	4.08	61.7	44.5	20.1
	24	5	4	6	4.59	4.29	7.24	2.76	3.26	5.81	63.7	42.3	35.7
	36	6	11	4	6.30	6.08	10.25	3.87	3.95	8.48	62.2	57.8	31.6
SE	12	6	5	11	2.03	2.60	5.96	1.24	1.49	4.03	62.3	67.0	54.4
	24	4	8	10	3.72	4.85	10.43	2.46	2.57	6.90	56.4	71.8	56.3
	36	5	7	9	5.20	6.97	13.83	3.45	3.97	9.52	56.0	67.5	52.6
All	12	6	9	10	2.69	2.42	5.55	1.57	1.60	3.96	65.9	56.3	49.0
	24	7	10	11	4.69	4.46	9.54	2.87	2.95	6.50	62.7	56.1	53.7
	36	8	17	11	6.31	6.37	12.70	4.02	4.09	8.86	59.4	58.8	51.4

*Including upper-air predictors.

TABLE 6-9
RMS ERRORS IN TESTS ON WINTER CYCLONES,
1959-1960 (INDEPENDENT SAMPLE)

Zone	n	Forecasts interval, hr	Northward displacement, deg lat				Eastward displacement, deg lat				Change in central pressure, mb			
			Modified base test	Unstrat	Strat	Climatol	Modified base test	Unstrat	Strat	Climatol	Modified base test	Unstrat	Strat	Climatol
NW	43	12	1.70	1.39	1.35	2.25	1.22	1.16	1.27	2.52	4.06	3.95	4.50	4.39
		24	3.23	2.00	2.07	4.06	2.29	2.16	2.38	4.74	7.05	6.90	6.85	7.57
		36	3.92	3.99	4.65	5.61	3.21	3.72	4.10	6.64	10.42	10.80	10.10	10.46
NE	34	12	1.89	1.73	1.66	2.72	1.49	1.51	2.50	2.87	4.36	3.86	3.99	4.20
		24	3.32	3.3	2.55*	4.79	2.69	2.70	3.33	5.46	6.58	5.76	7.98	7.96
		36	4.65	4.76	4.78	5.32	4.09	4.45	6.01	7.71	8.99	9.24	10.19	11.25
SW	69	12	1.73	1.72	1.9	2.39	1.9	1.62*	1.95	2.08	4.0	4.07	4.49	4.60
		24	3.0	3.1	3.54	4.3	3.2	3.4	3.1	3.76	6.99	7.6	7.16	7.35
		36	4.20	4.35	4.99	5.91	[illegible]	4.68	4.29	4.81	8.0	8.61	9.99	8.52
SE	6	12	1.31	1.38	1.46	2.0	[illegible]	2.01	2.0	2.24	4.58	4.7	4.52	6.12
		24	2.16	2.14	2.0	3.42	[illegible]	3.4	[illegible]	[illegible]	[illegible]	[illegible]	6.95	9.44
		36	3.58	3.5	3.	4.6	[illegible]	4.84	[illegible]	[illegible]	8.20	[illegible]	8.52	11.7

*Significant at the 5% level.

Table 6-9 shows the rms errors, by zone, found in applying the two sets (stratified and unstratified) of derived equations. For comparison, the rms errors resulting from the application of the base-technique equations to the same sample are included.

Student's t-test for paired comparisons indicated that equations that include past history as predictors yield improvements in two instances that are statistically significant at less than the 5% level. One is the application to the southwestern zone of the 12-hr eastward-displacement equation derived from the unstratified developmental sample. The other is the application to the northeastern zone of the 24-hr northward-displacement equation derived from the stratified sample.

6.1.4 Results of Incorporating Additional Derived Predictors

After the necessary reduction of possible derived predictors was made by the method described in Section 5.0, two screening-regression experiments were performed. Results of the test on independent data were compared with those of the modified base technique.

The two experiments employing additional derived predictors were limited to consideration of the three 24-hr predictands, and equations were derived using only the unstratified developmental sample. The first screening-regression experiment considered the possible predictors listed in Table 5-2. The second experiment considered, in addition, the three past-history predictors.

The results of the screening-regression analysis are summarized in Tables 6-10 and 6-11. Table 6-10 lists the predictors in the order of their selection by the screening procedure and the percentage of the total variance of the predictand explained by each. Table 6-11 contains a summary of the initial and residual standard deviations and the percent reductions.

Table 6-12 summarizes the results, by zone, of the application of the equations to the independent data sample of 213 cases. Also included are the results obtained by the modified base technique.

TABLE 6-10
PREDICTORS SELECTED BY SCREENING REGRESSION
FOR WINTER CYCLONES OVER NORTH AMERICA
(INCLUDING DERIVED PREDICTORS)

Forecast interval, hr	Order of selection	$\hat{N}$		$\hat{E}$		$\hat{D}$	
		Predictor	% red	Predictor	% red	Predictor	% red
24*	1st	v_7	33.6	u_7	29.3	$\|v\|$	19.8
	2nd	λ	8.2	$Z(12,10)$	10.1	λ	7.9
	3rd	$P(16, 6)$	4.1	$A_H\ (9,7)$	4.3	$\Delta Z(9, 8)$	5.6
	4th	$A_{H7}(9,6)$	3.3	$\Delta Z(6, 5)$	2.9	$P(10, 5)$	4.8
	5th	Δu_7	2.5	$Z(11, 1)$	1.9	$\Delta Z(10, 3)$	3.4
	6th	$P(10, 6)$	2.8	v_7	2.0	$A_H\ (6,4)$	3.1
	7th	$\zeta_T(8, 8)$	1.1	$\Delta\zeta_T(10,9)$	1.2	$A_{\zeta T}(9,10)$	1.4
	8th	$Z(14, 4)$	1.1	$P(5, 5)$	1.0	$A_H\ (9, 7)$	1.4
	9th	$H\ (6, 8)$	1.9	$P(17, 3)$	1.0	$\Delta P(9, 6)$	2.9
	10th	$H_7(12,2)$	1.2	$A_{\zeta T}(13,4)$	0.9	$\dot{v}_7$	1.2
	11th	-	-	-	-	$\Delta P(10, 3)$	1.2
Total			59.8		54.6		52.7
24†	1st	$\Delta\phi$	39.7	$\Delta\lambda$	30.5	$\|v\|$	19.8
	2nd	$Z(14, 4)$	7.4	u	8.9	λ	7.9
	3rd	$Z(7, 7)$	6.3	$Z(12,10)$	6.1	$\Delta Z(9, 8)$	5.6
	4th	λ	2.8	v_7	3.4	$P(10, 5)$	4.8
	5th	$\zeta_T(8, 8)$	1.7	$H\ (6, 8)$	2.2	$\Delta Z(10, 3)$	3.4
	6th	$P(10, 6)$	1.3	$\Delta\zeta_T(10,9)$	1.1	$A_H\ (6,4)$	3.1
	7th	$H_7(12,2)$	1.3	$P(13, 1)$	1.0	ΔP_c	2.1
	8th	Δu_7	1.2	$A_H\ (9,7)$	0.8	$A_{\zeta T}(9,10)$	1.2
	9th	$\|v\|$	0.9	$H_7(12,2)$	0.8	$A_H\ (9, 7)$	1.4
	10th	$\zeta_T(14,12)$	0.7	v_7	0.9	$\Delta P(9, 6)$	1.6
	11th	-	-	$P(5, 9)$	0.9	$\dot{v}_7$	1.1
	12th	-	-	$\dot{v}_7$	0.8	$\Delta P(10,3)$	1.0
	13th	-	-	$A_{H7}(6,9)$	0.9	-	-
Total			63.3		58.3		53.0

*Excluding past history.
†Including past history.

TABLE 6-11
RESULTS OF SCREENING REGRESSION* ON WINTER CYCLONES OVER NORTH AMERICA,
1955-1959 (DEPENDENT SAMPLE)

Zone	Forecast interval, hr	No. of predictors			Std dev			Residual std dev			% reduction		
		$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$
All*†	24	10	10	11	4.69	4.46	9.54	2.97	3.00	6.56	59.8	54.6	52.7
All‡	24	10	13	12	4.69	4.46	9.54	2.84	2.88	6.54	65.3	58.3	55.0

*Including derived predictors.
†Excluding past history.
‡Including past history.

TABLE 6-12
RMS ERRORS IN TESTS ON WINTER CYCLONES,
1959-1960 (INDEPENDENT SAMPLE)

Zone	n	Forecast interval, hr	Northward displacement, deg lat				Eastward displacement, deg long				Change in central pressure, mb			
			Modified base tech	Unstratified		Climatol	Modified base tech	Unstratified		Climatol	Modified base tech	Unstratified		Climatol
				Derived terms without past history	Derived terms with past history			Derived terms without past history	Derived terms with past history			Derived terms without past history	Derived terms with past history	
NW	43	12	1.70	-	-	2.23	1.22	-	-	2.52	4.06	-	-	4.39
		24	3.23	2.62*	2.72	4.06	2.29	2.65	2.54	4.74	[illegible]	6.75	6.74	7.37
		36	3.52	-	-	5.67	3.21	-	-	6.64	10.42	-	-	10.46
NE	34	12	1.85	-	-	2.72	1.49	-	-	2.87	4.36	-	-	4.20
		24	2.95	3.56	3.48	4.78	2.69	2.97	3.26	3.46	6.38	6.86	6.70	7.96
		36	4.65	-	-	5.82	4.09	-	-	7.71	8.99	-	-	11.25
SW	69	12	1.73	-	-	2.59	1.62	-	-	2.08	4.07	-	-	4.60
		24	3.07	3.05	3.19	4.39	3.52	4.04	3.56	3.76	6.99	6.68	6.69	7.35
		36	4.20	-	-	5.81	4.94	-	-	4.81	8.90	-	-	8.52
SE	67	12	1.31	-	-	2.07	1.95	-	-	2.24	4.58	-	-	6.12
		24	2.16	2.44	2.30	3.42	3.26	3.31	3.30	3.95	6.90	6.70	6.76	9.44
		36	3.58	-	-	4.65	4.42	-	-	3.73	8.20	-	-	11.75

*Significant at the 5% level.

An examination of Table 6-12 reveals improvement over the base technique in five of the 12 comparisons. However, only application to the northwestern zone of the derived-term (without past history) equation for 24-hour northward displacement yielded an improvement statistically significant at less than the 5% level. The base technique was modified to include this equation.

6.1.5 Results of the Application of Prediction Equations Using Surface Data Only

To make the prediction technique applicable to those synoptic observation times for which upper-air observations are not available, equations were derived from sets of possible predictors containing only surface data. Two screening-regression experiments excluding possible upper-air predictors were carried out. The experiments were identical except that three additional possible predictors (past history) were included in the second experiment.

In these experiments, prediction equations were derived for a cyclone's 12- and 24-hr displacements and changes in central pressure. The possible predictors common to both experiments are given in Table 5-3.

Results of the screening-regression analysis are summarized in Tables 6-13 and 6-14. Table 6-13 lists the predictors in the order of their selection by the screening procedure and the percentage of the total variance of the predictand explained by each. Table 6-14 summarizes the initial and residual standard deviations and the percent reductions.

Table 6-15 summarizes the results of testing the equations derived from surface predictors on the independent data sample. The results obtained from the base-technique equations are also included.

Although the overall performance of the base technique is slightly superior to that of the equations derived only from surface predictors, it appears that useful results can be obtained from the surface-predictor equations when upper-air data are not available. Note from Table 6-15 that the 12-hr change-in-central-pressure equation based only on surface data and past history yielded a considerably smaller

TABLE 6-13
PREDICTORS SELECTED BY SCREENING REGRESSION*
FOR WINTER CYCLONES OVER NORTH AMERICA

(a) Excluding past history

Forecast interval, hr	Order of selection	$\hat{N}$		$\hat{E}$		$\hat{D}$	
		Predictor	% red	Predictor	% red	Predictor	% red
12	1st	λ	22.6	P(13,11)	14.6	ΔP(9, 5)	13.4
	2nd	P(15, 7)	8.7	ΔP(7, 5)	7.4	λ	6.9
	3rd	P(10, 6)	7.0	P(11, 1)	4.6	P(10, 5)	4.7
	4th	ΔP(9, 7)	2.8	P(6, 6)	2.5	P(11, 5)	6.2
	5th	ΔP(7, 3)	2.7	P(13, 7)	2.5	ΔP(5, 3)	3.5
	6th	P(11, 7)	2.3	P(17, 3)	3.0	ΔP(10, 4)	3.0
	7th	P(6, 2)	2.3	P(9, 3)	1.9	ΔP(10, 8)	2.1
	8th	P(13, 3)	1.6	ΔP(10, 4)	2.7	P(17, 5)	1.2
	9th	ΔP(10, 2)	1.8	P(7, 1)	1.8	P(6, 6)	0.8
	10th	ΔP(11, 9)	1.0	P(13, 5)	1.7	ΔP(8, 6)	1.1
	11th	P(3, 9)	1.1	P(14, 4)	0.9	-	-
	12th	P(13, 1)	0.7	ΔP(8, 6)	0.8	-	-
	13th	-	-	ΔP(3, 5)	1.0	-	-
Total			54.6		45.4		42.9
24	1st	λ	22.3	P(13,11)	16.9	λ	13.4
	2nd	P(17, 7)	7.8	P(13, 1)	7.5	ΔP(9, 3)	7.0
	3rd	P(10, 6)	6.0	P(13, 7)	3.1	ΔP(5, 3)	4.5
	4th	P(14, 4)	3.6	λ	3.1	P(10, 5)	5.5
	5th	P(7, 1)	2.5	ϕ	3.7	ΔP(10, 6)	4.5
	6th	ΔP(7, 1)	2.4	ΔP(7, 5)	1.8	P(12, 6)	4.8
	7th	ΔP(9, 7)	1.6	P(5, 7)	2.1	P(17, 3)	2.5
	8th	P(11, 7)	2.2	P(10, 2)	2.5	ΔP(10, 4)	1.1
	9th	ΔP(11, 9)	1.0	ΔP(11, 5)	1.3	P(11, 1)	1.8
	10th	P(1, 7)	1.1	P(17, 3)	1.4	-	-
	11th	P(15, 7)	1.1	P(9, 7)	0.9	-	-
Total			51.6		45.8		45.1

*Excluding upper-air predictors.

(b) Including past history

Forecast interval, hr	Order of selection	$\hat{N}$ Predictor	$\hat{N}$ % red	$\hat{E}$ Predictor	$\hat{E}$ % red	$\hat{D}$ Predictor	$\hat{D}$ % red
12	1st	$\Delta\phi$	51.4	$\Delta\lambda$	35.0	$\Delta P(9, 5)$	13.4
	2nd	λ	3.0	$P(13,11)$	4.3	λ	6.9
	3rd	$P(17, 7)$	2.0	$P(10, 2)$	1.7	$P(10, 5)$	4.7
	4th	$P(11, 7)$	2.1	$P(12, 6)$	2.6	$P(11, 5)$	6.2
	5th	$P(14, 6)$	1.3	λ	1.7	$\Delta P(5, 3)$	3.5
	6th	ϕ	1.2	$P(15, 3)$	1.3	$\Delta P(10, 4)$	3.0
	7th	$P(13, 3)$	0.6	$\Delta P(8, 6)$	1.0	$\Delta\phi$	3.7
	8th	$\Delta P(9, 3)$	0.7	ϕ	1.1	ΔP_c	2.0
	9th	-	-	$P(5, 7)$	1.3	-	-
	10th	-	-	$\Delta P(11, 5)$	1.0	-	-
	11th	-	-	$P(10, 6)$	1.3	-	-
Total			62.3		52.3		43.4
24	1st	$\Delta\phi$	39.7	$\Delta\lambda$	30.5	λ	13.4
	2nd	λ	4.5	$P(13,11)$	6.3	$\Delta P(9, 3)$	7.0
	3rd	$P(17, 7)$	4.0	$P(13, 1)$	2.4	$\Delta P(5, 3)$	4.5
	4th	$P(11, 7)$	3.9	λ	2.1	$P(10, 5)$	5.5
	5th	$\Delta P(15, 5)$	1.2	ϕ	2.2	ΔP_c	4.7
	6th	ϕ	1.2	$P(13, 7)$	2.8	$P(11, 5)$	3.3
	7th	$P(14, 4)$	0.8	$P(3, 3)$	1.2	$\Delta P(10, 5)$	4.5
	8th	$\Delta P(11, 9)$	0.6	$P(17, 3)$	1.0	$\Delta\phi$	1.7
	9th	$\Delta P(10, 6)$	0.7	$P(9, 3)$	1.1	$P(11, 7)$	1.1
	10th	$\Delta P(11, 3)$	0.7	$\Delta P(13, 5)$	0.9	$P(17, 3)$	1.3
	11th	-	-	$\Delta P(8, 6)$	0.8	-	-
	12th	-	-	$P(6, 8)$	1.2	-	-
Total			57.3		52.5		47.0

TABLE 6-14

RESULTS OF SCREENING REGRESSION* ON WINTER CYCLONES OVER NORTH AMERICA, 1955-1959 (DEPENDENT SAMPLE)

Zone	Forecast interval, hr	No. of predictors			Std dev			Residual std dev			% reduction		
		$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$
All†	12	12	13	10	2.69	2.42	5.55	1.81	1.56	4.19	54.6	45.4	42.9
	24	11	11	9	4.69	4.46	9.54	3.27	3.28	7.07	51.6	45.8	45.1
All‡	12	8	11	8	2.69	2.42	5.55	1.65	1.67	4.17	62.3	52.3	43.4
	24	10	12	10	4.69	4.46	9.54	3.07	3.07	6.94	57.3	52.5	47.0

*Excluding upper-air predictors.
†Excluding past history.
‡Including past history.

TABLE 6-15
RMS ERRORS IN TESTS ON WINTER CYCLONES,
1959-1960 (INDEPENDENT SAMPLE)

Zone	n	Forecast interval, hr	Northward displacement, deg lat: Modified base tech	Northward displacement, deg lat: Unstratified: Surface without past history	Northward displacement, deg lat: Unstratified: Surface with past history	Northward displacement, deg lat: Climatol	Eastward displacement, deg lat: Modified base tech	Eastward displacement, deg lat: Unstratified: Surface without past history	Eastward displacement, deg lat: Unstratified: Surface with past history	Eastward displacement, deg lat: Climatol	Change in central pressure, mb: Modified base tech	Change in central pressure, mb: Unstratified: Surface without past history	Change in central pressure, mb: Unstratified: Surface with past history	Change in central pressure, mb: Climatol
NW	45	12	1.70	1.66	1.73	2.23	1.22	1.59	1.24	2.52	4.06	3.85	3.78	4.39
		24	2.62	2.89	2.93	4.06	2.29	3.10	2.89	3.74	7.05	7.40	6.70	7.37
		36	3.52	-	-	3.67	3.21	-	-	6.64	10.42	-	-	10.46
NE	54	12	1.83	1.98	1.97	2.72	1.49	1.80	1.65	2.87	4.36	4.38	3.79*	4.20
		24	2.95	3.62	3.67	4.78	2.69	3.36	3.77	5.46	6.38	7.38	6.75	7.95
		36	4.63	-	-	5.82	4.09	-	-	7.71	8.99	-	-	11.25
SW	69	12	1.73	1.75	1.65	2.99	1.62	1.97	1.74	2.08	4.07	4.20	4.09	4.60
		24	3.07	3.73	3.30	4.99	3.52	3.65	3.50	3.76	6.99	6.91	6.52	7.35
		36	4.20	-	-	5.81	4.94	-	-	4.81	8.90	-	-	8.52
SE	67	12	1.31	1.54	1.58	2.07	1.95	2.05	2.06	2.24	4.58	5.04	4.93	6.12
		24	2.16	2.69	2.43	3.42	3.26	3.17	3.46	3.95	6.90	7.34	7.28	9.44
		36	3.58	-	-	4.65	4.42	-	-	3.73	8.20	-	-	11.75

*Significant at the 5% level.

TABLE 6-16
VERIFICATION OF OPERATIONAL APPLICATION

Forecast interval, hr	No. of cases	Vector-position rms error, deg lat: Base tech	Vector-position rms error, deg lat: Strat	Vector-position rms error, deg lat: NMAC	Central-pressure rms error, mb: Base tech	Central-pressure rms error, mb: Strat	Central-pressure rms error, mb: NMAC
12	81	2.16	2.39	-	3.96	6.07	-
24	81	3.98	4.08	-	9.82	10.29	-
36	65	3.67	5.90	-	11.86	12.00	-
24	57*	3.95	4.13	4.05	9.60	10.04	8.48
36	30*	6.29	5.97	5.47	10.12	8.72	12.81

*Comparable cases for regression and NMAC.

rms error in the northeastern zone than the base technique did. Student's t-test for paired comparisons indicates that the improvement is significant at less than the 5% level. The inclusion of this equation represents the final modification made to the base technique in this study.

6.1.6 Operational Tests

To assess the accuracy of the regression technique, the unimproved base-technique equations were applied to all cyclones identified in the area defined by Fig. 2-1 between November 1962 and March 1963, and the results were compared with NWAC 24- and 36-hr prognoses received by facsimile. The vector-position rms errors and the central-pressure rms errors are shown in Table 6-16. Included also are the results of the stratified-sample equations. NWAC prognoses were available for 57 of the eighty-one 24-hr forecasts* and 30 of the sixty-five 36-hr forecasts.

The table indicates that, for this sample, the base technique continued to perform well in comparison with stratification. The 36-hr reduced-sample forecast of central pressure is the only important exception. The comparisons with the NWAC prognoses indicate that the base technique was better for 24-hr position and 36-hr pressure, but the NWAC prognoses were better for 24-hr pressure and 36-hr position.

6.2 Summer Cyclones

Prediction experiments similar to, but fewer than, the winter series were conducted to develop prediction equations for the behavior of summer cyclones over North America. The number of cases available for development of the summer equations and the number of independent cases for testing the results are given in Table 2-1.

Two sets of prediction equations were derived for application at observation times for which both surface and upper-air observations are available; their

*In some cases the cyclone under consideration was off the edge of the NWAC facsimile map.

TABLE 6-17
PREDICTORS SELECTED BY SCREENING REGRESSION*
FOR SUMMER CYCLONES OVER NORTH AMERICA

(a) Excluding past history

Forecast interval, hr	Order of selection	$\hat{N}$		$\hat{E}$		$\hat{D}$	
		Predictor	% red	Predictor	% red	Predictor	% red
12	1st	ΔP(9, 7)	9.3	Z(11, 9)	16.4	ΔP(9, 5)	7.9
	2nd	P(15, 7)	7.0	Z(9, 3)	19.4	P(10, 5)	3.4
	3rd	P(11, 7)	8.0	Z(11, 7)	5.3	P(11, 5)	5.1
	4th	ΔP(7, 5)	3.2	H(13, 5)	2.1	ΔP(7, 5)	5.5
	5th	ΔP(11, 9)	2.1	Z(3, 7)	1.7	ΔP(10, 5)	2.7
	6th	λ	2.1	P(11, 1)	1.6	ΔP(7, 3)	1.4
	7th	P(9, 1)	2.1	ΔP(11, 7)	0.8	-	-
	8th	Z(9, 7)	1.3	ΔP(9, 5)	1.4	-	-
	9th	Z(13, 5)	13.3	ΔZ(11, 3)	0.7	-	-
	10th	H(13, 3)	1.5	ΔZ(7, 5)	1.0	-	-
	11th	P(15, 9)	1.3	-	-	-	-
	12th	H(9, 5)	1.1	-	-	-	-
	13th	P(5, 1)	0.9	-	-	-	-
	14th	ΔP(10, 5)	0.9	-	-	-	-
	15th	ΔP(11, 3)	1.1	-	-	-	-
Total			55.2		50.4		26.0
24	1st	P(15, 7)	10.3	Z(11, 9)	18.5	P(10, 5)	7.3
	2nd	P(11, 7)	8.6	Z(9, 3)	22.9	ΔP(10, 5)	10.4
	3rd	ΔP(9, 7)	4.7	Z(11, 7)	5.1	P(11, 5)	7.4
	4th	ΔP(7, 5)	5.3	Z(3, 7)	1.7	ΔP(7, 3)	2.8
	5th	λ	2.2	H(13, 5)	2.5	-	-
	6th	P(9, 1)	2.8	P(15, 3)	1.6	-	-
	7th	H(9, 7)	2.0	Z(11, 5)	0.9	-	-
	8th	Z(13, 5)	15.0	ΔZ(11, 7)	1.2	-	-
	9th	Z(15,11)	1.8	ΔZ(7, 5)	1.8	-	-
	10th	Z(7, 1)	1.7	-	-	-	-
	11th	H(5, 1)	1.1	-	-	-	-
	12th	ΔP(10, 5)	0.8	-	-	-	-
	13th	H(13, 3)	0.7	-	-	-	-
	14th	ΔP(11, 3)	1.0	-	-	-	-
Total			58.0		54.2		27.9

*Including upper-air predictors.

(b) Including past history

Forecast interval, hr	Order of selection	$\hat{N}$		$\hat{E}$		$\hat{D}$	
		Predictor	% red	Predictor	% red	Predictor	% red
12	1st	ΔΦ	29.2	Δλ	29.8	ΔP(9, 5)	7.9
	2nd	P(15, 7)	3.4	Z(11, 9)	5.2	Δλ	4.1
	3rd	P(11, 7)	4.1	Z(9, 3)	8.9	P(10, 5)	3.5
	4th	ΔP(9, 7)	2.9	Z(11, 7)	2.6	P(11, 5)	5.1
	5th	Δλ	1.4	ΔP(9, 5)	1.5	ΔP(7, 3)	4.3
	6th	ΔP(13, 9)	1.1	ΔP(13, 5)	1.6	ΔP(10, 5)	1.8
	7th	λ	0.8	ΔP(9, 3)	0.7	-	-
	8th	P(9, 1)	1.2	ΔZ(3, 7)	0.7	-	-
	9th	P(13, 3)	0.9	H(13, 5)	1.2	-	-
	10th	ΔP(11, 3)	0.9	-	-	-	-
	11th	H(9, 7)	0.9	-	-	-	-
	12th	Z(13, 7)	7.5	-	-	-	-
Total			54.3		52.2		26.7
24	1st	ΔΦ	22.6	Δλ	23.4	P(10, 5)	7.3
	2nd	P(15, 7)	5.2	Z(11, 9)	7.8	ΔP(10, 5)	10.4
	3rd	P(11, 7)	6.5	Z(9, 3)	13.7	P(11, 5)	7.4
	4th	Z(9, 7)	2.1	Z(11, 7)	1.7	ΔP(7, 3)	2.8
	5th	Z(13, 5)	13.6	ΔP(9, 3)	1.8	P(11, 9)	1.1
	6th	Z(15,11)	1.8	ΔP(13, 5)	2.0	ΔP(15, 7)	0.8
	7th	Φ	2.0	ΔZ(11, 7)	1.1	ΔΦ	0.7
	8th	P(5, 1)	1.0	ΔZ(7, 5)	1.4	H(7, 7)	0.6
	9th	H(9, 5)	1.2	-	-	H(11, 1)	1.4
	10th	ΔP(11, 7)	1.1	-	-	ΔZ(9, 5)	1.5
	11th	-	-	-	-	ΔZ(5, 1)	3.3
Total			57.1		52.9		37.3

TABLE 6-18
RESULTS OF SCREENING REGRESSION* ON SUMMER CYCLONES OVER NORTH AMERICA, 1955-1959 (DEPENDENT SAMPLE)

Zone	Forecast interval, hr	No. of predictors			Std dev			Residual std dev			% reduction		
		$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$
All*	12	15	10	6	2.04	2.02	3.73	1.36	1.42	3.20	55.2	50.4	26.0
	24	14	9	4	3.58	3.69	5.57	2.32	2.50	4.72	58.0	54.2	27.9
All†	12	12	9	6	2.04	2.02	3.73	1.38	1.39	3.19	54.3	52.2	26.7
	24	10	8	11	3.58	3.69	5.57	2.35	2.53	4.41	57.1	52.9	37.3

*Excluding past history.
†Including past history.

TABLE 6-19
RMS ERRORS IN TESTS* ON SUMMER CYCLONES OVER NORTH AMERICA, 1959 (INDEPENDENT SAMPLE)

Forecast interval, hr	Northward displacement, deg lat			Eastward displacement, deg lat			Vector, deg lat			Change in central pressure, mb		
	Without past history	With past history	Climatol	Without past history	With past history	Climatol	Without past history	With past history	Climatol	Without past history	With past history	Climatol
12	1.66	1.62	2.22	1.78	1.73	2.20	2.44	2.37	3.13	3.46	3.42	3.74
24	3.00	2.93	3.86	3.13	2.97	3.89	4.34	4.17	5.48	5.88	5.54	6.06

*Including upper-air predictors.

derivation and testing are discussed in Section 6.2.1. Two other sets of prediction equations were derived for application at observation times for which only surface data are available; their results are discussed in Section 6.2.2.

6.2.1 Results of Using Both Surface and Upper-air Predictors

The first equations derived were to be applicable to all cyclones in the entire North American prediction area (Fig. 2-1) for 0000 and 1200 GCT when both upper-air and surface data are available. To make the equations applicable to newly formed cyclones, the motion and change in central pressure of the cyclone just prior to forecast time were not considered as possible predictors. The predictands for all summer-cyclone prediction experiments were the 12- and 24-hr displacement components and the 12- and 24-hr change in central pressure. The possible predictors for this first experiment are listed in Table 5-1. The second summer-cyclone experiment using both surface and upper-air predictors was the same as the first except that the three past-history predictors (Table 3-2) were included.

The results of these two screening-regression analyses are summarized in Tables 6-17 and 6-18. Table 6-17 lists the predictors in the order of their selection and the percentage of the variance of the predictand explained by each. Table 6-18 summarizes the results of application of the derived equations to the developmental sample.

Table 6-19 lists the rms errors resulting from the application of the equations to the independent data sample (169 cases). The rms errors associated with the equations using past-history predictors are only slightly lower than those obtained from application of the equations not using past-history predictors.

6.2.2 Results of Using Surface Predictors Only

To make the technique applicable to observation times for which only surface data are available, two sets of equations were derived with only surface parameters considered for screening. The set of possible predictors for the first experiment is listed in Table 5-3. The second experiment, using only surface

TABLE 6-20
PREDICTORS SELECTED BY SCREENING REGRESSION*
FOR SUMMER CYCLONES OVER NORTH AMERICA

(a) Excluding past history

Forecast interval, hr	Order of selection	$\hat{N}$		$\hat{E}$		$\hat{D}$	
		Predictor	% red	Predictor	% red	Predictor	% red
12	1st	ΔP(10, 6)	13.0	P(12, 8)	11.1	ΔP(9, 5)	7.9
	2nd	P(15, 7)	7.2	P(11, 1)	9.0	P(7, 5)	5.3
	3rd	P(11, 7)	4.2	ΔP(8, 6)	4.3	P(10, 8)	2.9
	4th	ΔP(12, 8)	3.3	ΔP(11, 5)	3.0	P(10, 5)	2.4
	5th	ΔP(9, 7)	2.7	P(10, 5)	2.5	P(11, 5)	4.6
	6th	λ	2.0	P(12, 6)	4.0	ΔP(8, 4)	3.2
	7th	P(9, 1)	1.9	-	-	ΔP(15, 3)	1.8
	8th	ΔP(8, 4)	1.6	-	-	ΔP(10, 4)	1.4
	9th	P(11, 3)	1.5	-	-	-	-
	10th	P(15,11)	1.6	-	-	-	-
Total			39.0		33.9		29.5
24	1st	P(15, 7)	10.3	P(13, 9)	13.4	P(10, 5)	7.3
	2nd	P(10, 6)	10.8	P(12, 2)	7.4	ΔP(10, 5)	10.4
	3rd	λ	3.9	ΔP(8, 6)	3.7	P(11, 5)	7.4
	4th	ΔP(9, 7)	2.4	ΔP(11, 7)	3.1	ΔP(7, 3)	2.8
	5th	ΔP(7, 5)	3.4	P(13, 5)	3.3	-	-
	6th	P(15,11)	1.9	λ	1.3	-	-
	7th	P(14, 4)	1.8	P(1, 7)	1.3	-	-
	8th	P(12, 6)	2.0	P(5, 3)	1.1	-	-
	9th	P(9, 1)	2.1	ΔP(11, 5)	1.3	-	-
	10th	P(9, 5)	1.8	P(10, 4)	2.1	-	-
	11th	ΔP(12, 8)	1.5	P(15, 3)	1.2	-	-
	12th	ΔP(10, 6)	0.9	-	-	-	-
	13th	ΔP(12, 4)	1.4	-	-	-	-
Total			44.2		39.2		27.9

*Excluding upper-air predictors.

(b) Including past history

Forecast interval, hr	Order of selection	$\hat{N}$		$\hat{E}$		$\hat{D}$	
		Predictor	% red	Predictor	% red	Predictor	% red
12	1st	$\Delta\phi$	29.2	$\Delta\lambda$	29.8	$\Delta P(9, 5)$	7.9
	2nd	$\Delta P(10, 6)$	3.5	$\Delta P(8, 6)$	3.1	$P(7, 5)$	5.3
	3rd	$P(15, 7)$	3.4	$P(13,11)$	2.3	$\Delta\lambda$	3.3
	4th	$P(11, 7)$	3.4	$P(10, 2)$	1.8	ΔP_c	1.6
	5th	ϕ	1.3	$P(12, 6)$	2.4	$P(10, 8)$	2.0
	6th	$\Delta P(12, 8)$	1.3	$\Delta P(12, 4)$	1.3	$\Delta P(17, 1)$	1.4
	7th	$\Delta P(1, 3)$	1.1	$P(10, 5)$	1.6	$P(10, 5)$	1.2
	8th	-	-	$\Delta P(11, 5)$	1.4	$P(10, 4)$	5.1
	9th	-	-	-	-	$P(11, 5)$	1.4
	10th	-	-	-	-	$\Delta P(8, 4)$	1.7
Total			43.2		43.7		30.9
24	1st	$\Delta\phi$	22.6	$\Delta\lambda$	23.4	$P(10, 5)$	7.3
	2nd	$P(15, 7)$	5.2	$P(13,11)$	6.3	$\Delta P(10, 5)$	10.4
	3rd	$P(11, 7)$	6.5	$\Delta P(8, 6)$	2.3	$P(11, 5)$	7.4
	4th	$\Delta\lambda$	1.9	$P(12, 2)$	2.1	$\Delta P(7, 3)$	2.8
	5th	$P(15,11)$	1.5	$P(13, 5)$	3.0	-	-
	6th	$\Delta P(13, 9)$	1.7	$\Delta P(12, 6)$	1.7	-	-
	7th	$\Delta P(9, 7)$	1.4	λ	1.6	-	-
	8th	$\Delta P(7, 5)$	1.9	-	-	-	-
	9th	ϕ	1.5	-	-	-	-
	10th	$P(14, 4)$	1.4	-	-	-	-
Total			45.6		40.4		27.9

TABLE 6-21
RESULTS OF SCREENING REGRESSION* ON SUMMER CYCLONES OVER NORTH AMERICA, 1955-1959 (DEPENDENT SAMPLE)

Zone	Forecast interval, hr	No. of predictors			Std dev			Residual std dev			% reduction		
		$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$
All†	12	10	6	8	2.04	2.02	3.73	1.59	1.64	3.13	39.0	33.9	29.5
	24	13	11	4	3.58	3.69	5.57	2.68	2.88	4.72	44.2	39.2	27.9
All‡	12	7	8	10	2.04	2.02	3.73	1.54	1.51	3.10	43.2	43.7	30.9
	24	10	7	4	3.58	3.69	5.57	2.64	2.85	4.72	45.6	40.4	27.9

*Excluding upper air predictors.
†Excluding past history.
‡Including past history.

TABLE 6-22
RMS ERRORS IN TESTS* ON SUMMER CYCLONES OVER NORTH AMERICA, 1959 (INDEPENDENT SAMPLE)

Forecast interval, hr	Northward displacement, deg lat			Eastward displacement, deg lat			Vector, deg lat			Change in central pressure, mb		
	Without past history	With past history	Climatol	Without past history	With past history	Climatol	Without past history	With past history	Climatol	Without past history	With past history	Climatol
12	1.83	1.69	2.22	1.95	1.77	2.20	2.67	2.45	3.13	3.47	3.42	3.74
24	3.29	3.13	3.86	3.37	3.14	3.89	4.71	4.43	5.48	5.58	5.58	6.06

*Surface predictors only.

predictors, was the same as the first except the three past-history predictors were included. Results of the analysis of the developmental sample for these two experiments are summarized in Tables 6-20 and 6-21.

The equations derived in the two experiments were applied to the 169 cases not used in their derivation. The results are presented in Table 6-22. The rms errors associated with the equations using past history as predictors are substantially lower than those not using past history for the two 12-hr displacement predictands; otherwise only slight, if any, improvements are realized.

7.0 OPERATIONAL APPLICATION OF THE PREDICTION TECHNIQUE

Tests on independent data reveal that the definition of best equations depends on storm location and availability of predictor data. Predictor availability can be divided conveniently into four cases:

Case 1. Surface and upper-air data are available, but past-history data are either not available or subject to large errors of estimation.

Case 2. Surface, upper-air, and past-history data are all available.

Case 3. Only surface data are available.

Case 4. Surface and past-history data are available, but upper-air data are not.

In Section 7.1, the recommended winter-cyclone equations to be used for each of the four data cases are indicated. A summary of the results of applying each of the four sets of equations to the independent data sample is presented. Section 7.2 indicates the recommended sets of equations for summer cyclones.

7.1 Winter Cyclones

Table 7-1 identifies the recommended equations for case 1 winter cyclones. All but two of the base-technique equations listed in Section B.1.1.5 should be used: $\hat{D}_{12}$ in the northeastern zone and $\hat{N}_{24}$ in the northwestern zone. Table 7-2 summarizes the results of applying this set of recommended prediction equations to the 213 independent cases.

Thirty-one of the 36 base-technique equations (Section B.1.1.5) apply to case 2 winter cyclones. Table 7-3 identifies the other five equations to be used. These are the five that produced statistically more significant results that the corresponding base-technique equations. Table 7-4 is a summary of the results of applying the recommended set of prediction equations to the 213 independent cases.

For case 3 winter cyclones, the equations listed in Section B.1.3 should be used.

For case 4 winter cyclones, the equations listed in Section B.1.4 should be used.

Results of applying the recommended case 3 and case 4 equations to the independent data sample are summarized in Table 7-5.

TABLE 7-1
RECOMMENDED EQUATIONS
FOR OPERATIONAL APPLICATION
FOR WINTER CYCLONES
WHERE SURFACE AND UPPER-AIR PREDICTORS
ARE AVAILABLE, BUT NOT PAST HISTORY

Zone	Time	$\hat{N}$	$\hat{E}$	$\hat{D}$
NW	12	*	*	*
	24	B.1.5	*	*
	36	*	*	*
NE	12	*	*	B.1.3
	24	*	*	*
	36	*	*	*
SW	12	*	*	*
	24	*	*	*
	36	*	*	*
SE	12	*	*	*
	24	*	*	*
	36	*	*	*

* = B.1.1.5.

TABLE 7-3
RECOMMENDED EQUATIONS FOR OPERATIONAL APPLICATION
FOR WINTER CYCLONES WHERE SURFACE,
UPPER-AIR,
AND PAST-HISTORY PREDICTORS ARE AVAILABLE

Zone	Time	$\hat{N}$	$\hat{E}$	$\hat{D}$
NW	12	*	*	*
	24	B.1.5	*	*
	36	B.1.1.1	*	*
NE	12	*	*	B.1.3
	24	B.1.2.2	*	*
	36	*	*	*
SW	12	*	B.1.2.5	*
	24	*	*	*
	36	*	*	*
SE	12	*	*	*
	24	*	*	*
	36	*	*	*

* = B.1.1.5

TABLE 7-2
RMS ERRORS FOR WINTER CYCLONES, PAST-HISTORY PREDICTORS NOT AVAILABLE

Zone	12-hr predictands			24-hr predictands			36-hr predictands			Vector error, deg lat		
	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	12-hr	24-hr	30-hr
NW	1.70	1.22	4.06	2.62	2.29	7.05	4.15	3.21	10.42	2.09	3.48	5.25
NE	1.83	1.49	3.79	3.52	2.69	6.38	4.63	4.09	8.99	2.36	4.43	6.18
SW	1.73	1.90	4.07	3.07	3.52	6.99	4.20	4.94	8.90	2.57	4.67	6.48
SE	1.31	1.95	4.58	2.16	3.26	6.90	3.58	4.42	8.20	2.35	3.91	5.69
All	1.62	1.74	4.19	2.81	3.09	6.88	4.08	4.34	9.03	2.38	4.18	5.96

TABLE 7-4
RMS ERRORS FOR WINTER CYCLONES,
1959-1960 (INDEPENDENT SAMPLE)

Zone	12-hr predictands			24-hr predictands			36-hr predictands			Vector error, deg lat		
	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	12-hr	24-hr	36-hr
NW	1.70	1.22	4.06	2.62	2.29	7.05	3.52	3.21	10.42	2.09	3.48	4.76
NE	1.83	1.49	3.79	2.95	2.69	6.38	4.63	4.09	8.99	2.36	3.99	6.18
SW	1.73	1.62	4.07	3.07	3.52	6.99	4.20	4.94	8.90	2.37	4.67	6.48
SE	1.31	1.95	4.38	2.16	3.26	6.90	3.58	4.42	8.20	2.35	3.91	5.69
All	1.62	1.64	4.19	2.70	3.09	6.88	3.96	4.34	9.03	2.31	4.1C	5.88

TABLE 7-5
SUMMARY OF RMS ERRORS ON WINTER CYCLONES,
INDEPENDENT DATA (213 CASES)

	12-hr predictands				24-hr predictands			
	Northward displacement	Eastward displacement	Vector	Change in central pressure	Northward displacement	Eastward displacement	Vector	Change in central pressure
Surface and past-history predictors	1.70	1.75	2.44	4.27	3.04	3.42	4.58	6.84
Surface predictors only	1.71	1.89	2.55	4.44	3.07	3.35	4.54	7.22

TABLE 7-6
SUMMARY OF RMS ERRORS ON SUMMER CYCLONES,
INDEPENDENT DATA (169 CASES)

Predictors available	12-hr predictand				24-hr predictand			
	Northward displacement	Eastward displacement	Vector	Change in central pressure	Northward displacement	Eastward displacement	Vector	Change in central pressure
Surface, upper-air, past-history	1.62	1.73	2.37	3.42	2.93	2.97	4.17	5.54
Surface, upper-air	1.66	1.78	2.43	3.46	3.00	3.13	4.34	5.58
Surface, past-history	1.69	1.77	2.45	3.42	3.13	3.14	4.43	5.58
Surface	1.83	1.95	2.67	3.47	3.29	3.37	4.71	5.58

Although overall accuracy decreases somewhat as the number of available classes of predictors decreases, useful predictions appear to be possible despite incomplete data.

7.2 Summer Cyclones

Prediction equations for case 1 summer cyclones are listed in Section B.2.1.

Prediction equations for case 2 summer cyclones are listed in Section B.2.2.

Prediction equations for case 3 summer cyclones are listed in Section B.2.3.

Prediction equations for case 4 summer cyclones are listed in Section B.2.4.

Results of applying the four sets of equations to 169 independent cases are summarized in Table 7-6.

8.0 FORECAST EXAMPLES

From the 213 independent winter cases, six cyclones have been chosen to illustrate the applicability of certain characteristics of the forecast equations to a variety of forecast situations. Most of the forecasts selected were good (there is one poor forecast included); more representative verification statistics, based on the entire independent sample, can be found in Section 7.0.

The figures for this section are grouped at the end of the section. Each figure appears in two parts, (a) and (b). Part (a) is the surface chart at forecast (initial) time, with pressures indicated in millibars (hundreds' and thousands' digits deleted). Part (b) indicates the positions (reading generally from left to right) of the cyclone 12, 24, and 36 hr later: circles represent observed positions; squares represent positions forecast by the base technique on the unstratified data sample, using both surface and upper-air predictors; X's represent positions forecast by the modified technique (Section 7.0), which uses the optimum set of forecast equations; and triangles represent positions forecast by equations based only on surface and past-history predictors. Each symbol is accompanied by the appropriate central-pressure indication.

Tables following the figures summarize the pertinent verification statistics and correspond in numbering to the figures.

8.1 Two Northwestern-zone Cyclones

Figure 8-1 describes a cyclone that, at initial time 0000 GCT 18 Nov. 1959, was centered in Saskatchewan (54°N, 107°W) and had a central pressure of 1009 mb. The 500-mb chart at the same time (not shown) showed a broad northwesterly flow pattern from the Canadian Rockies to an intense trough over the Great Lakes.

One of the major problems presented to the synoptic forecaster in situations of cyclones under a northwesterly flow is determining if and when the cyclone will "recurve." This cyclone moved rapidly southeastward for the first 24 hr, then recurved to the northeast. Both the base and modified techniques gave sufficient

indication of likely recurvature in the 24-to-36-hr interval. The surface-only forecast, for which only 12- and 24-hr prediction equations were derived, appeared to predict recurvature at 24 hr. In no case, however, was the central-pressure forecast very good.

Figure 8-2 illustrates the forecast of a cyclone with an unusual track. The weak cyclone (1014 mb) over western Alberta (53°N, 117°W) at 1200 GCT 24 Feb. 1960 dropped nearly due southward for 36 hr, arriving in central Nevada, 850 naut mi south of its original position.

The modified technique produced the best forecast for this case, and, although the 36-hr displacement error was fairly large, the forecast was quite good qualitatively. The central-pressure forecasts indicated filling whereas in fact the cyclone deepened 11 mb in 36 hr.

8.2 Two Southeastern-zone Cyclones

Figure 8-3 describes a 1002-mb coastal disturbance that began off the New Jersey coast (38°N, 74°W) at 0000 GCT 19 Jan. 1960. It subsequently moved up the coast and turned eastward in Nova Scotia. At the end of the 36-hr period, the cyclone had deepened 24 mb, to 978 mb.

Both the base technique and the surface-only technique did quite well with this situation. The errors in displacement and intensification are small. Even the eastward turn was well handled.

Figure 8-4(a) is typical of many winter weather maps. In this instance (1200 GCT 18 Feb. 1960), there is a deepening cyclone (998 mb) on the Georgia-Alabama border (33°N, 85°W). The 500-mb chart (not shown) indicates a trough over the lower Mississippi Valley and a ridge through New England. Determining the future track of this class of cyclone is an important step in preparing a weather forecast for the North Atlantic states. This particular cyclone moved northeastward to the New England coast in 36 hr, with moderate deepening.

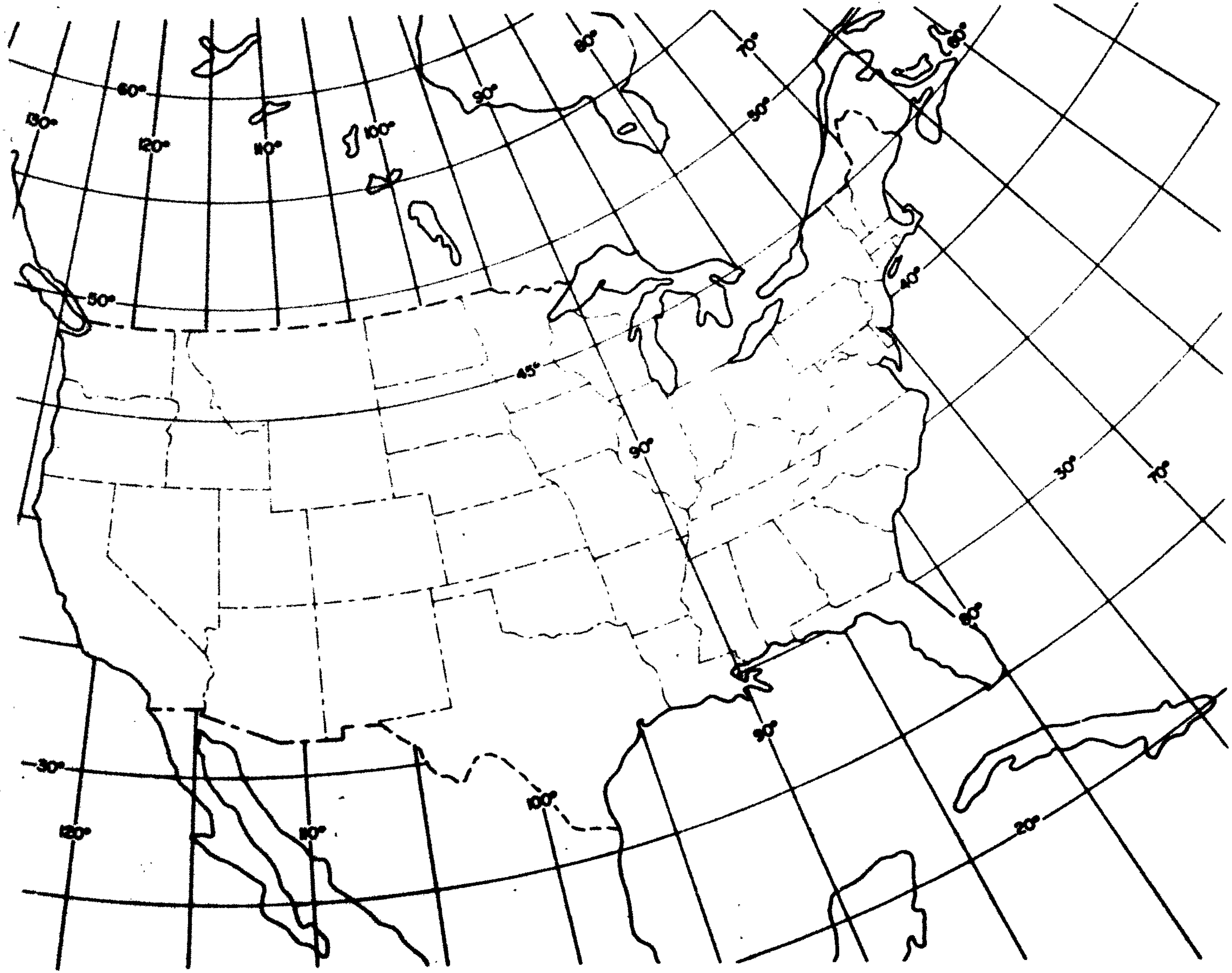
The displacement forecasts were exceptionally good, with an error of less than 50 naut mi for 36 hr.

8.3 Two Southwestern-zone Cyclones

Figure 8-5 illustrates one of the poorest forecasts of the entire independent sample. The surface chart for 0000 GCT 12 Jan. 1960 shows a 996-mb cyclone over eastern Oregon (44°N, 119°W). Although this cyclone moved southeastward into Arizona, all the techniques predicted that it would move pretty much due eastward; the 36-hr displacement error was very large.

Figure 8-6 represents a troublesome situation for synoptic forecasters. The deep cyclone (978 mb) over northeastern Colorado (41°N, 104°W) at 1200 GCT 9 Feb. 1960 had been moving southeastward for the previous 12 hr. The timing of recurvature is an important part of this forecast. After 12 hr of continued southeastward movement, the cyclone recurved northeastward, reaching the Michigan-Indiana border after 36 hr. The changes in central pressure were small; the cyclone remained quite intense during the entire forecast interval.

The forecasts, although not moving the cyclone fast enough, did a good job of capturing the recurvature by indicating a northeastward turn after 12 hr. The central-pressure forecasts were adequate.



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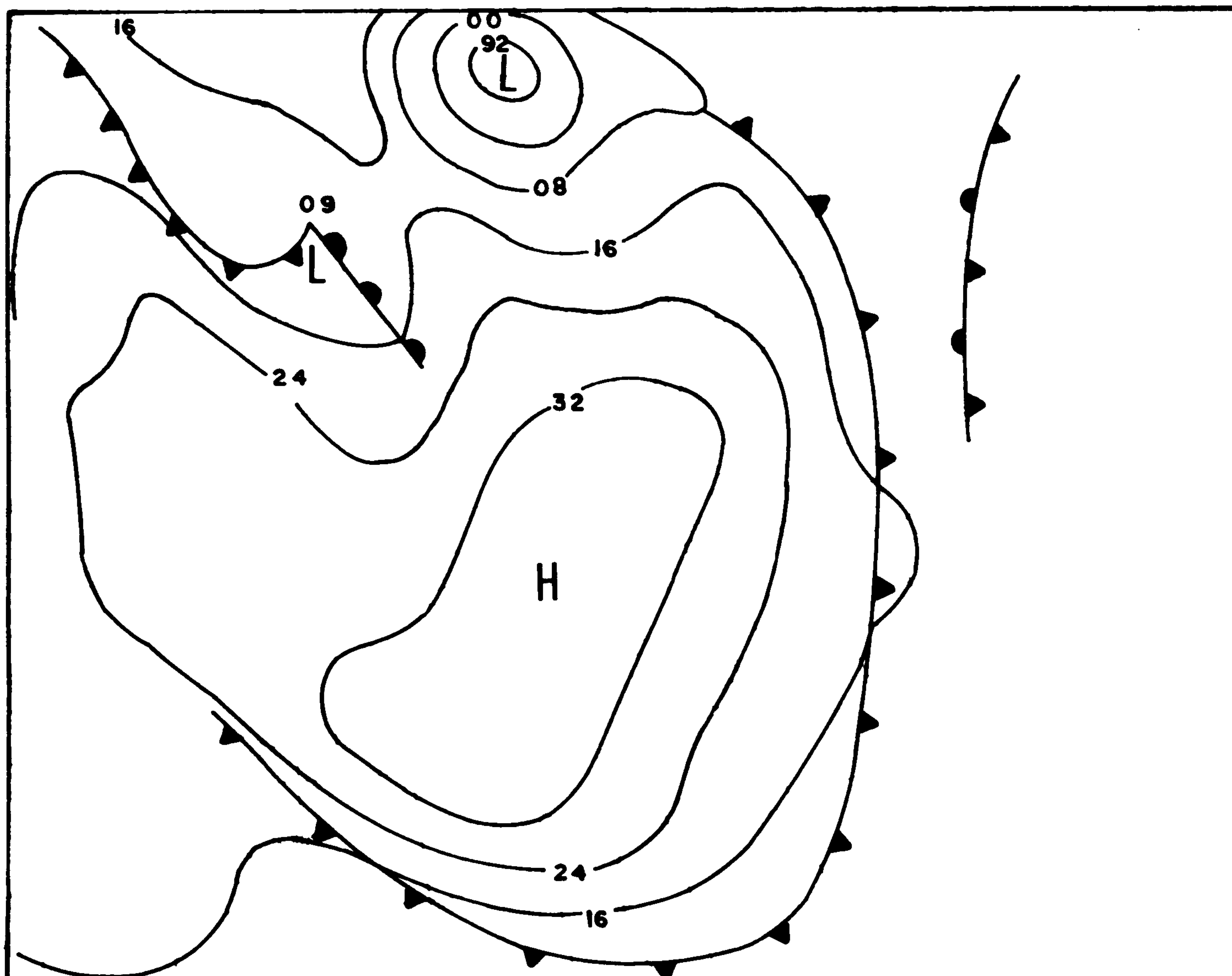

Fig. 8-1(a). First cyclone-forecast example. Initial conditions at 0000 GCT 18 Nov. 1959. Cyclone is located at 53.8°N, 107.0°W; central pressure is 1009 mb.

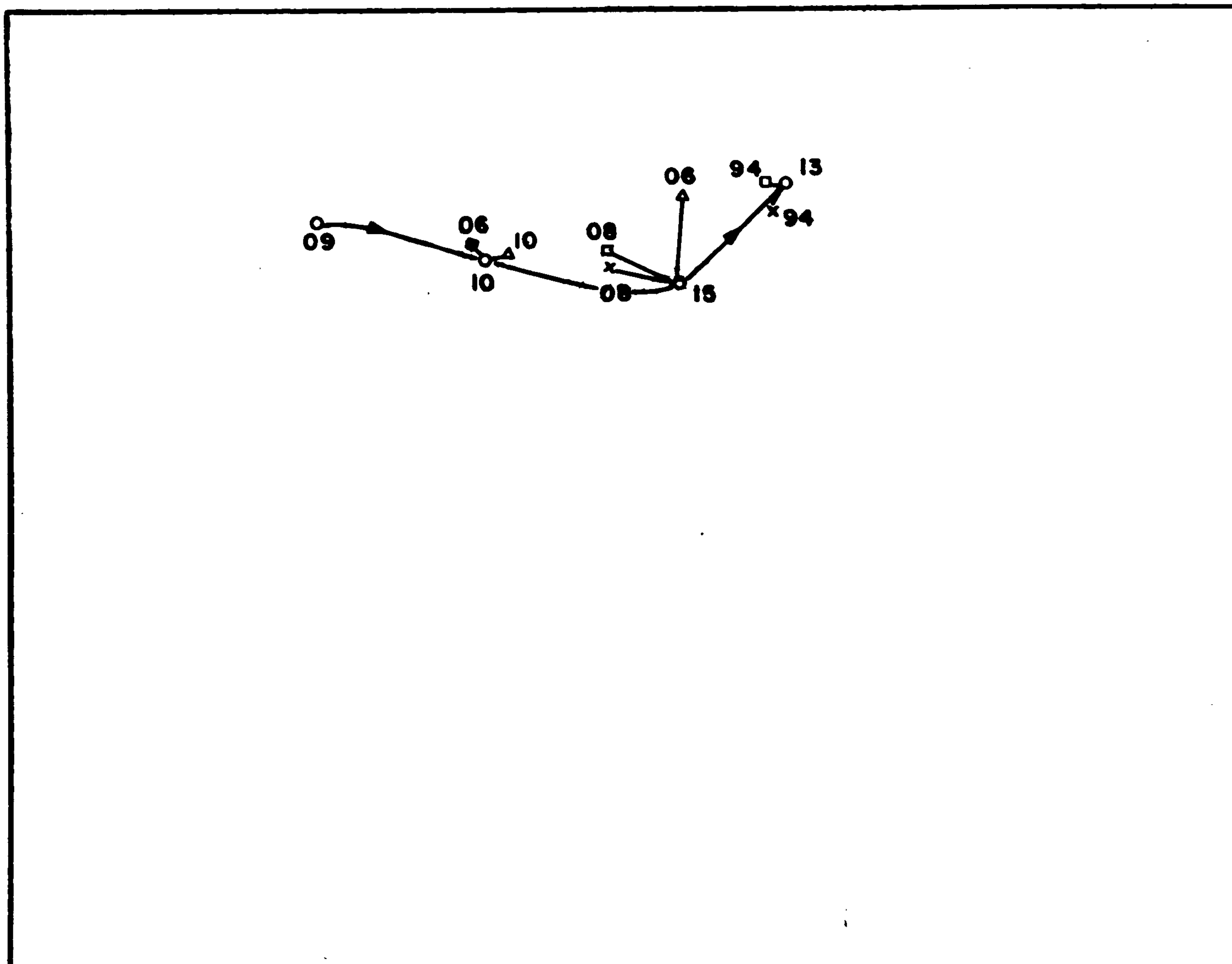

Fig. 8-1(b). Forecast verification. o observed, □ base technique, △ surface predictors only, x modified technique; adjacent numerals indicate central pressure.

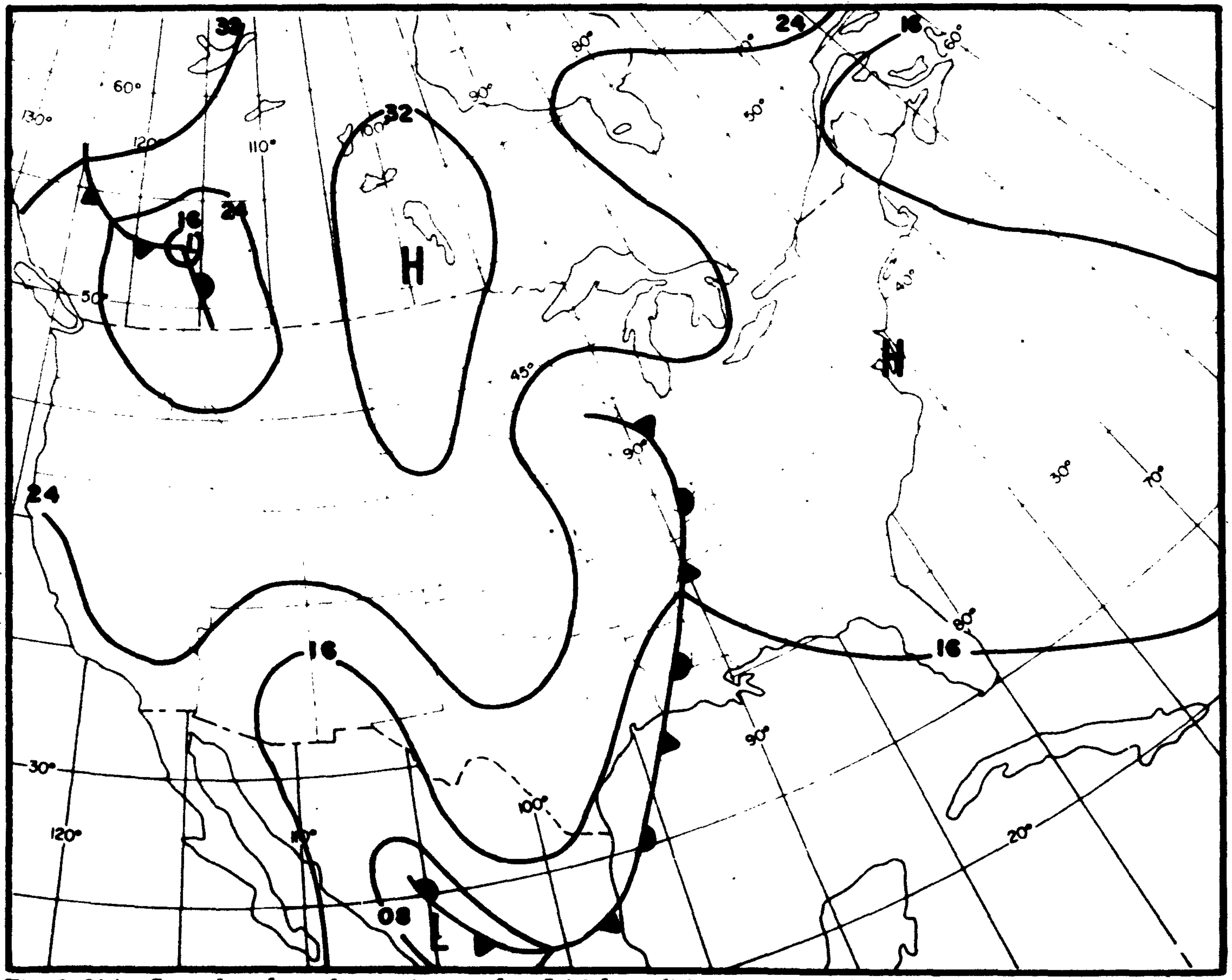

Fig. 8-2(a). Second cyclone-forecast example. Initial conditions at 1200 GCT 24 Feb. 1960. Cyclone is located at 52.8°N, 116.9°W; central pressure is 1014 mb.

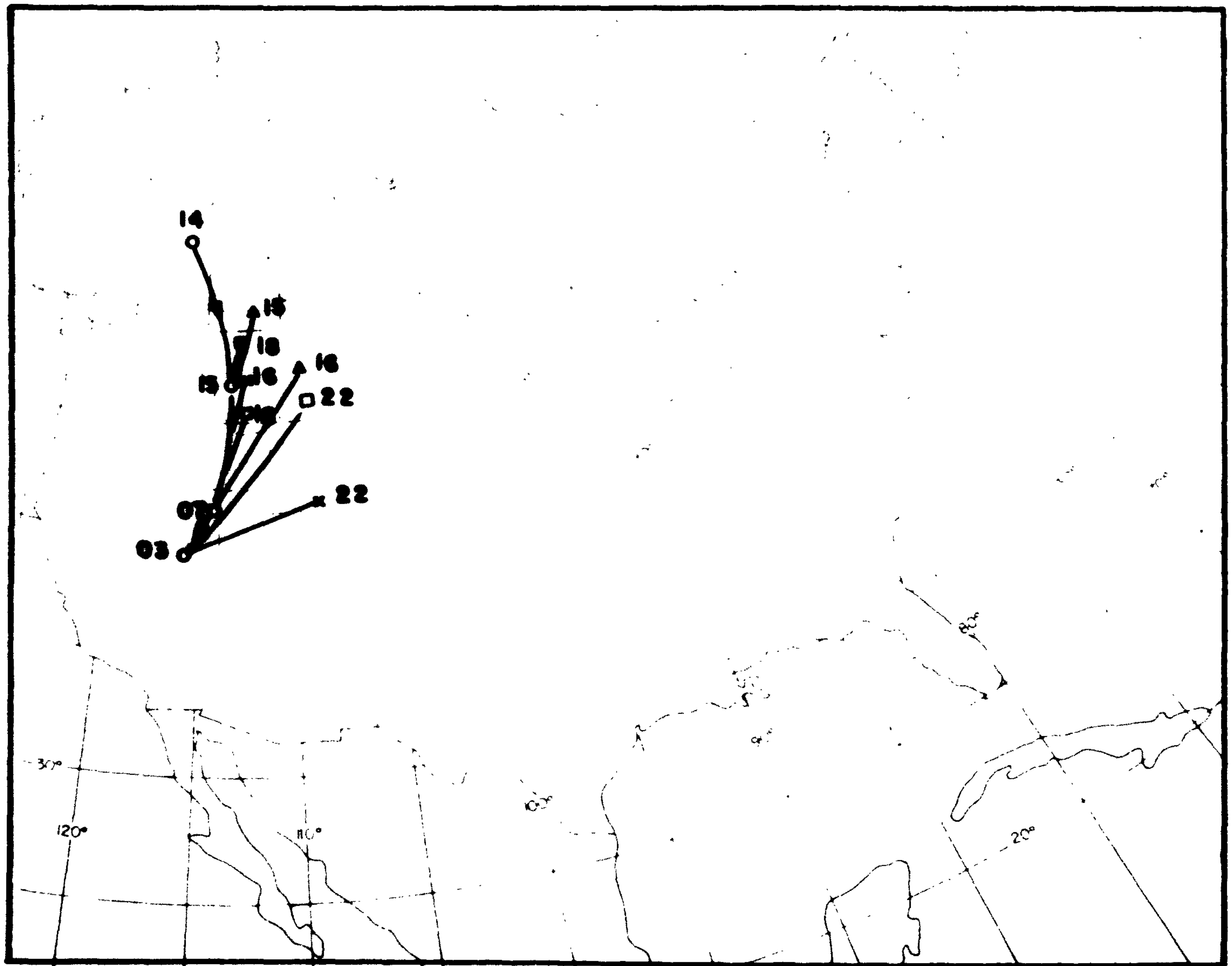

Fig. 8-2(b). Forecast verification. o observed, □ base technique, ▲ surface predictors only, x modified technique; adjacent numerals indicate central pressure.

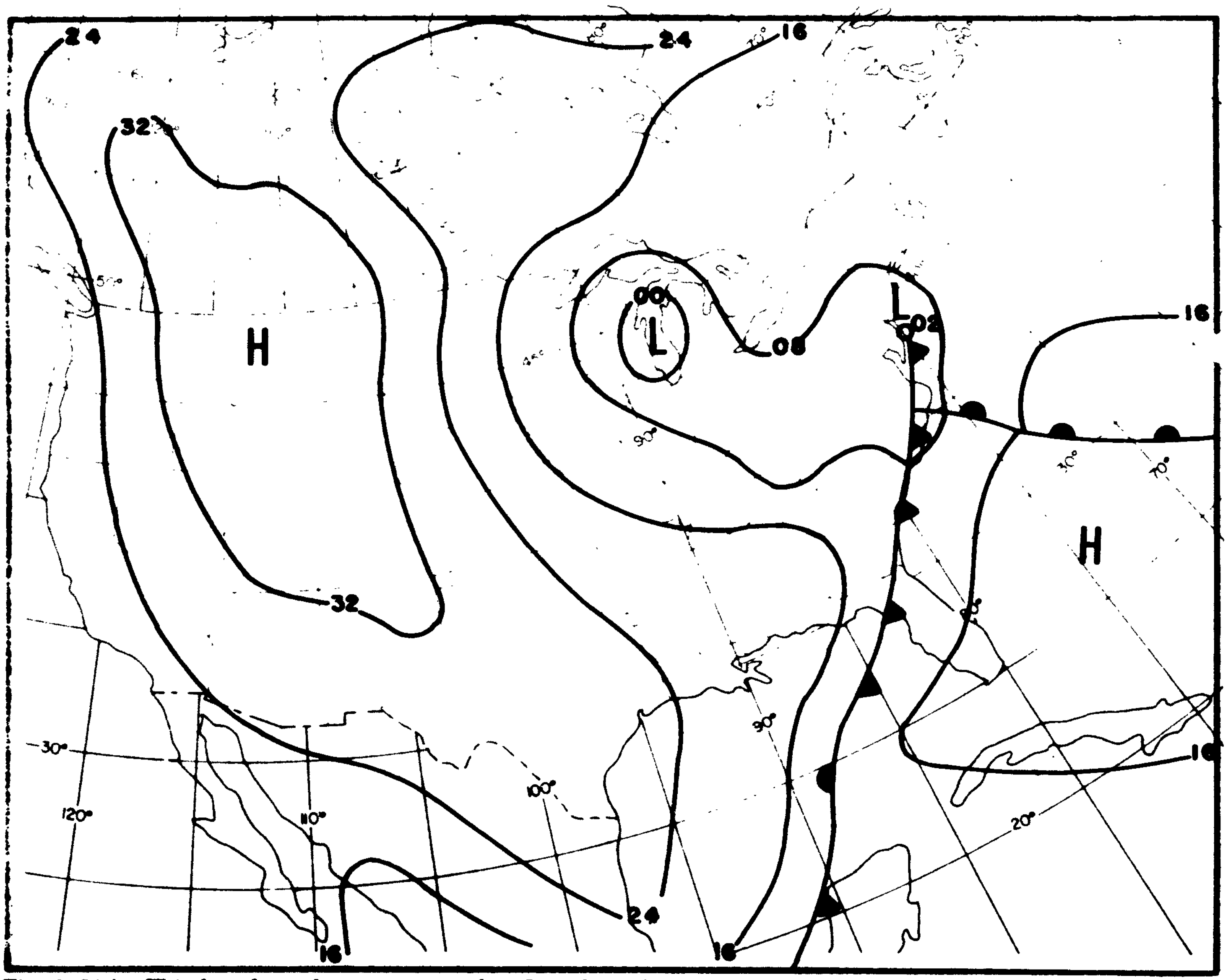

Fig. 8-3(a). Third cyclone-forecast example. Initial conditions at 0000 GCT 19 Jan. 1960. Cyclone is located at 38.1°N, 74.2°W; central pressure is 1002 mb.

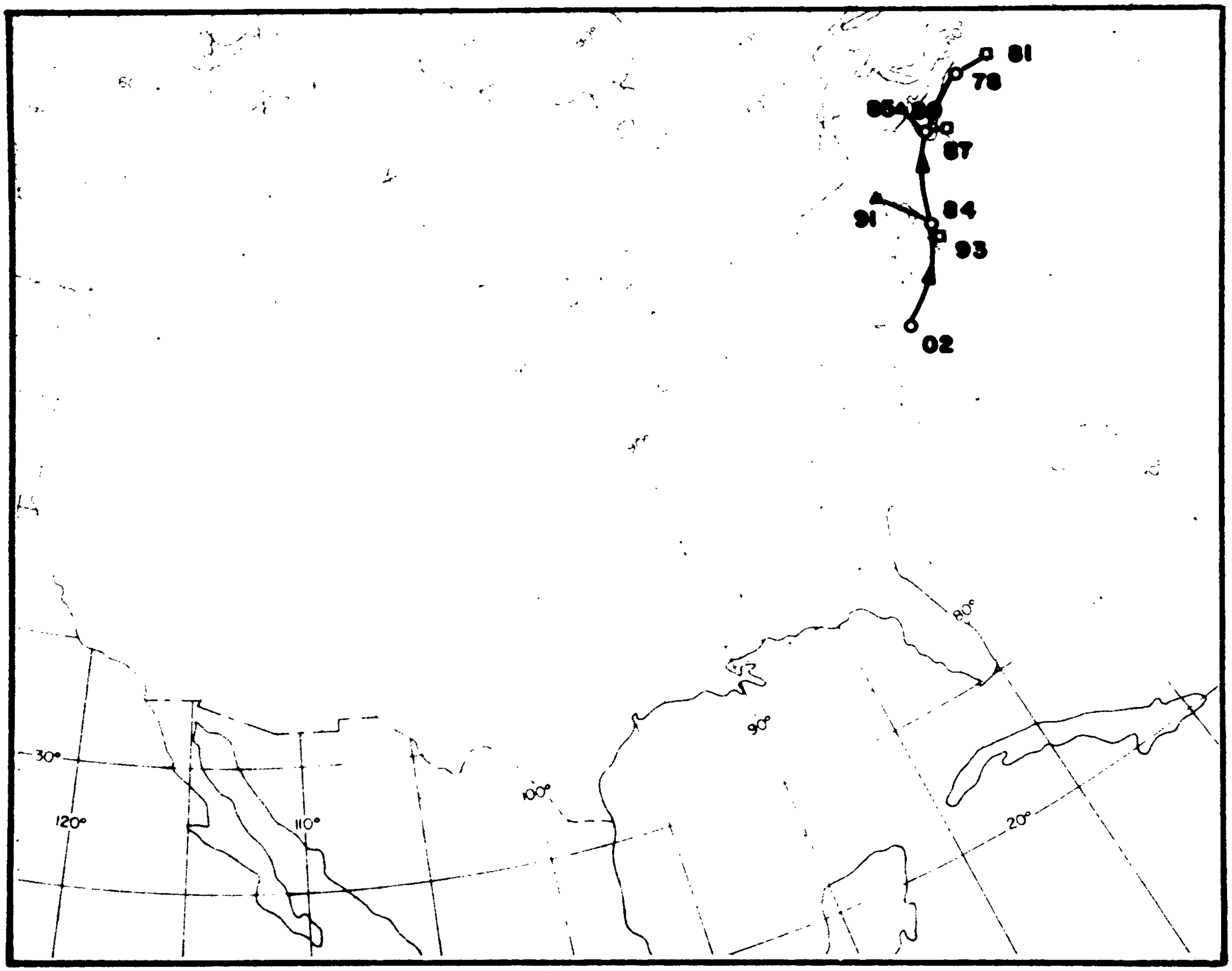

Fig. 8-3(b). Forecast verification. o observed, □ base technique, ▲ surface predictors only; adjacent numerals indicate central pressure.

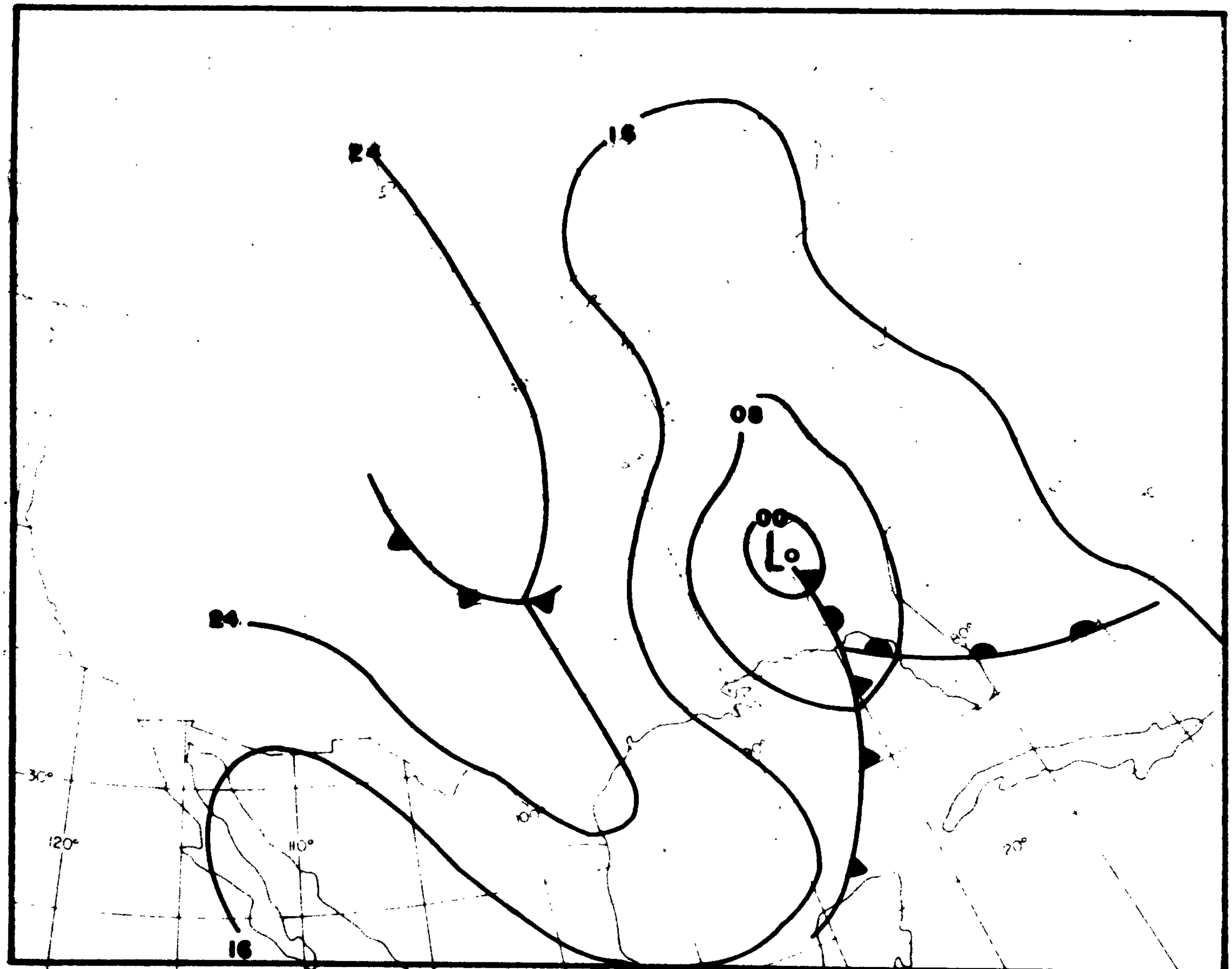

Fig. 8-4(a). Fourth cyclone-forecast example. Initial conditions at 1200 GCT 18 Feb. 1960. Cyclone is located at 33.3°N, 85.2°W; central pressure is 998 mb.

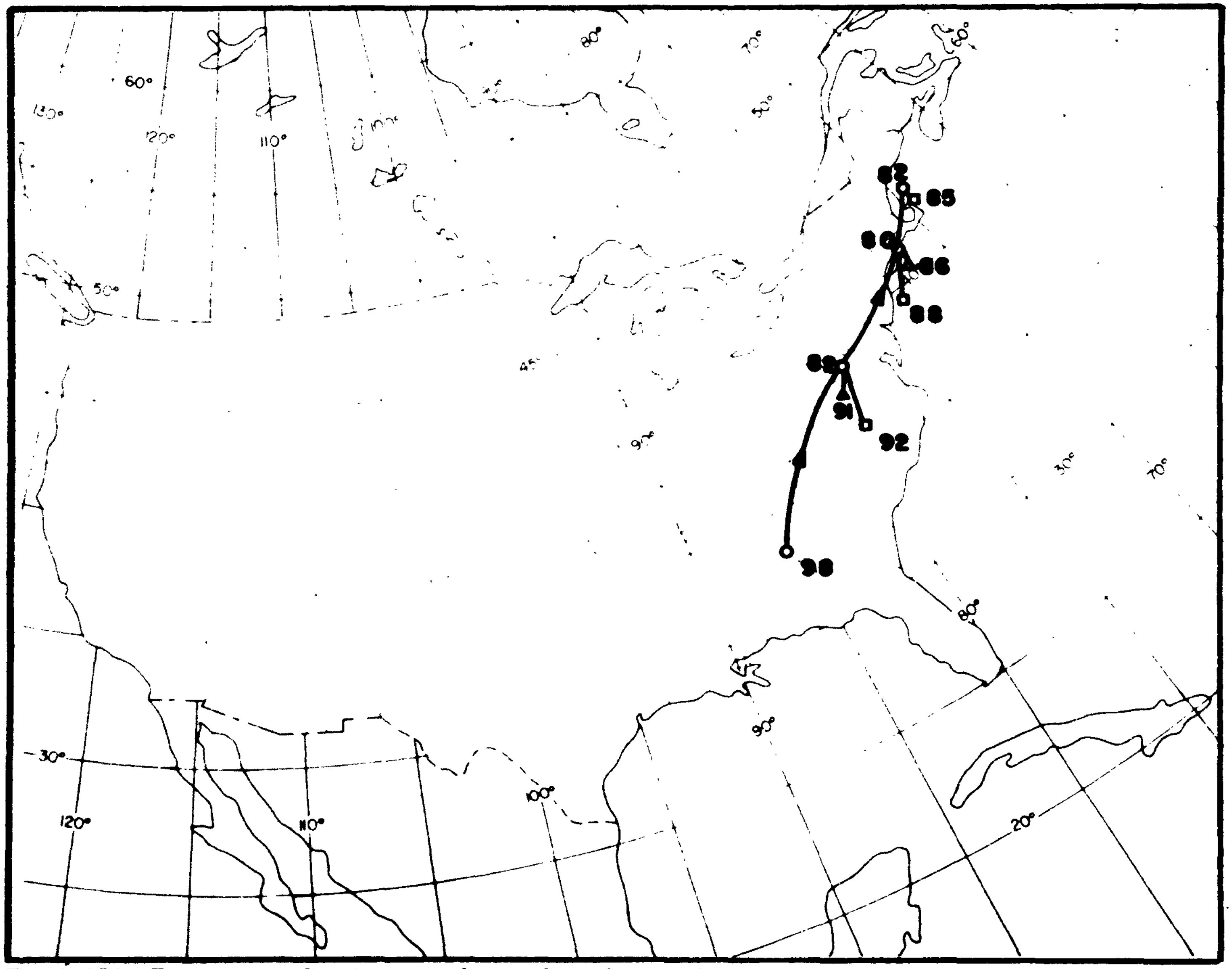

Fig. 8-4(b). Forecast verification. o observed, □ base technique, ▵ surface predictors only; adjacent numerals indicate central pressure.

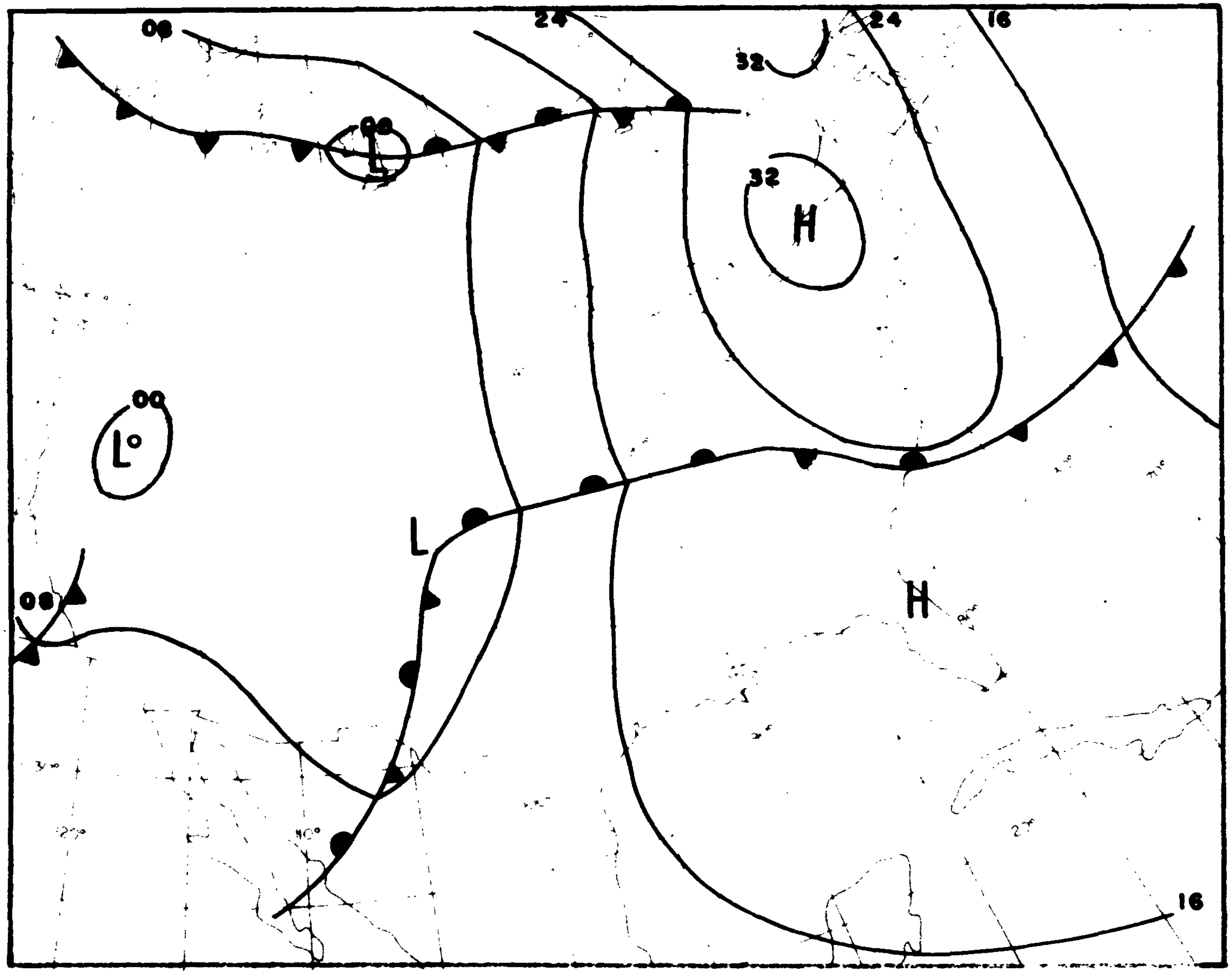

Fig. 8-5(a). Fifth cyclone-forecast example. Initial conditions at 0000 GCT 12 Jan. 1960. Cyclone is located at 43.6°N, 119.1°W; central pressure is 996 mb.

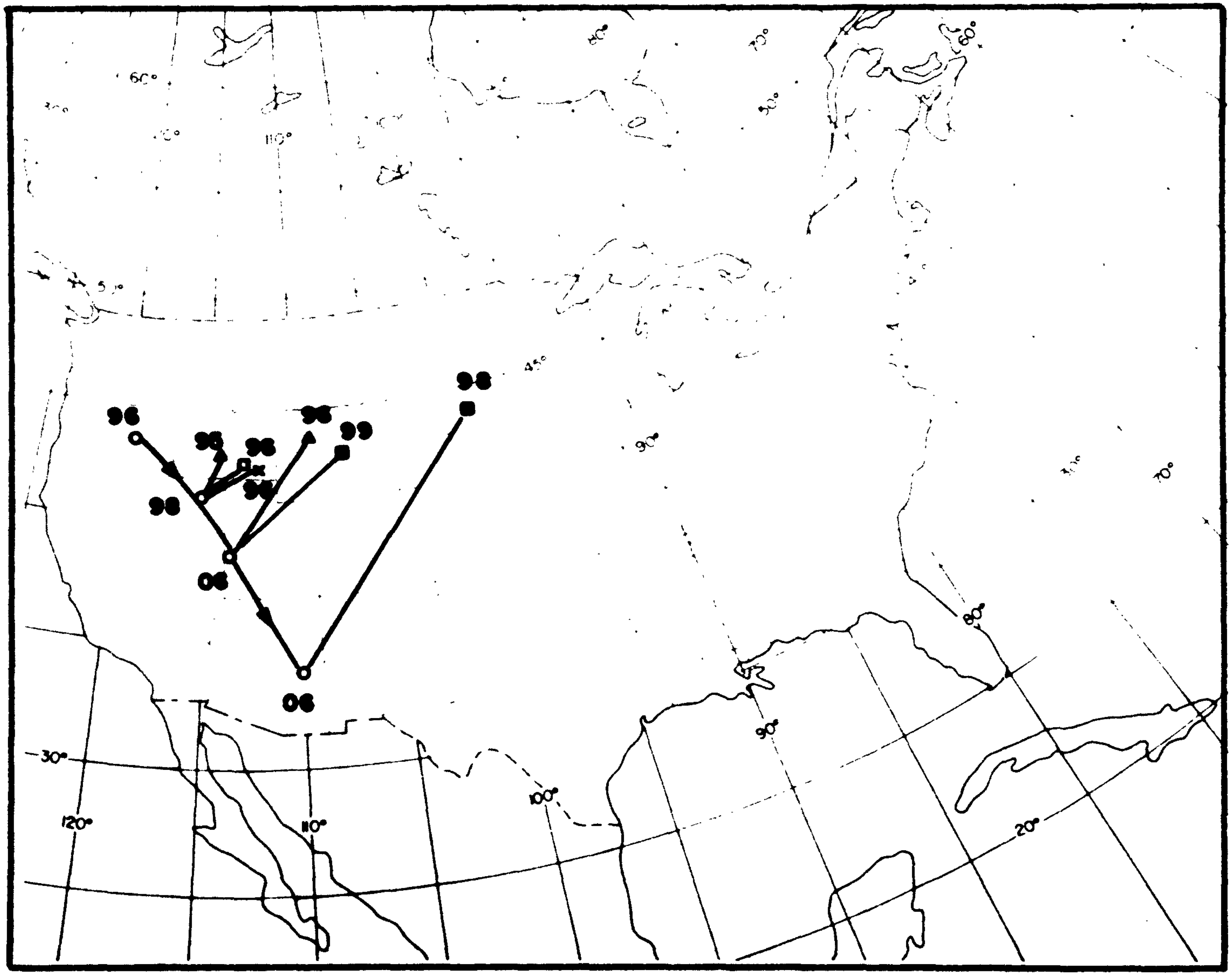

Fig. 8-5(b). Forecast verification. o observed, ▫ base technique, ▵ surface predictors only, x modified technique; adjacent numerals indicate central pressure.

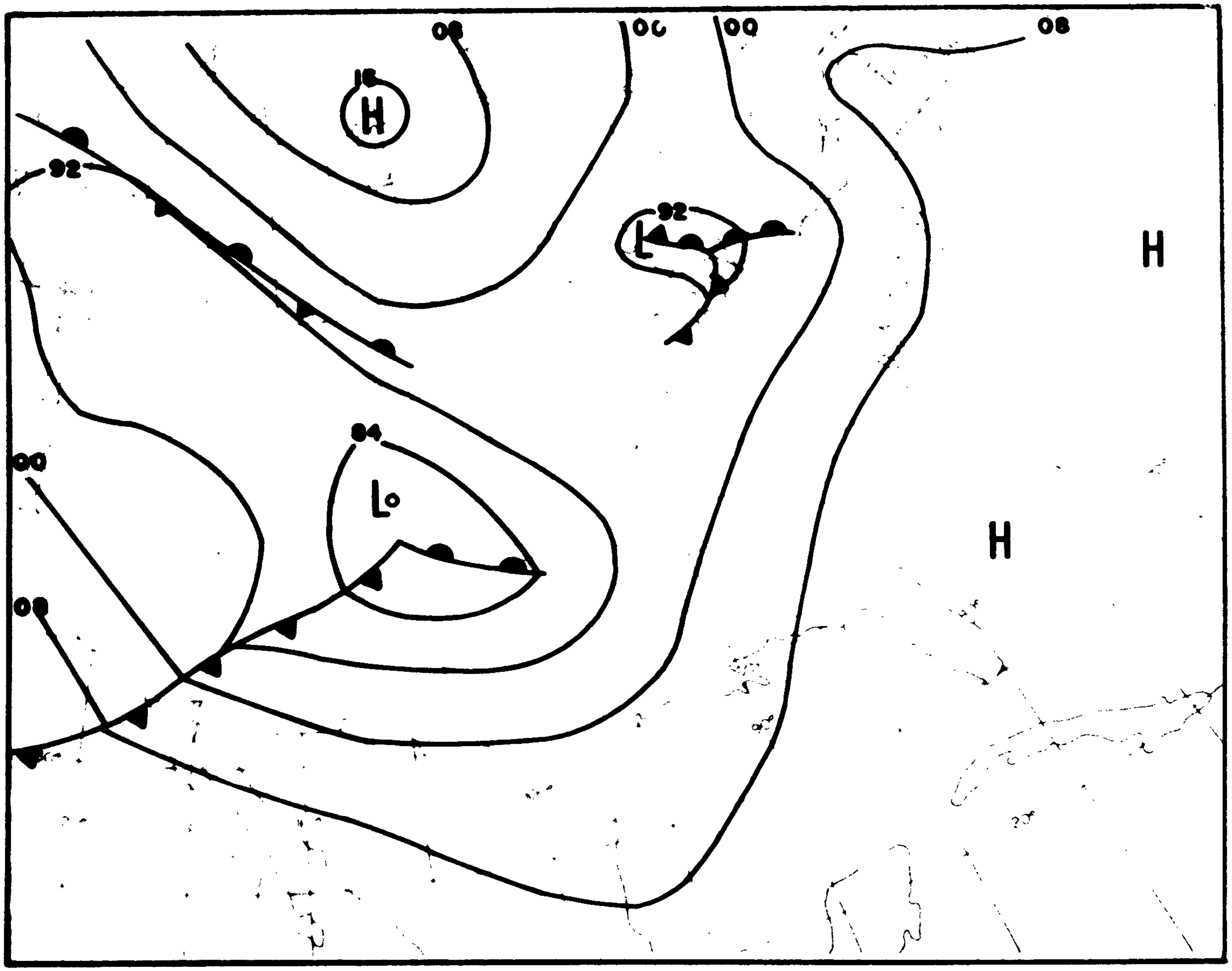

Fig. 8-6(a). Sixth cyclone-forecast example. Initial conditions at 1200 GCT 9 Feb. 1960. Cyclone is located at 41.3°N, 104.3°W; central pressure is 978 mb.

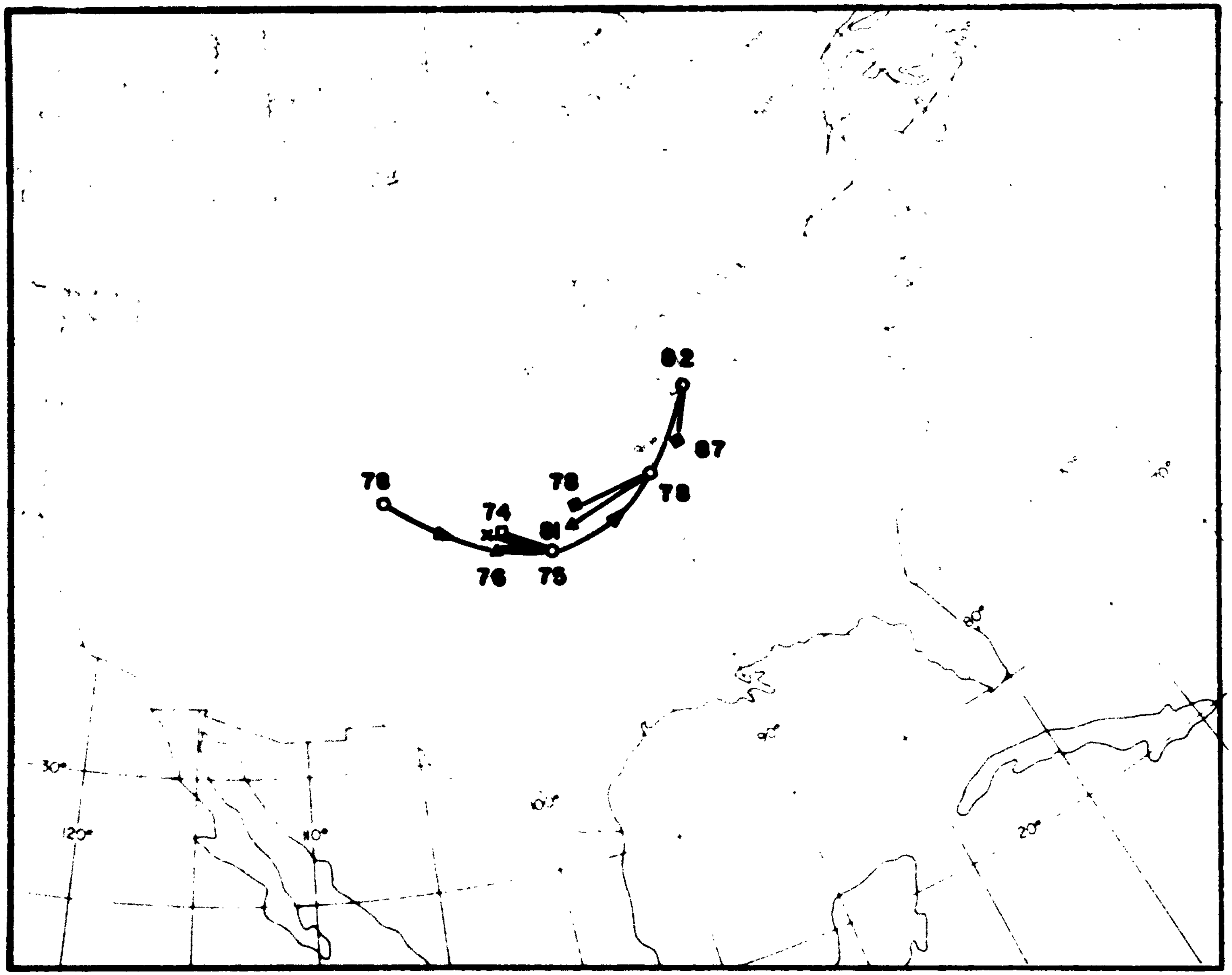

Fig. 8-6(b). Forecast verification. o observed, □ base technique, ▲ surface predictors only, x modified technique; adjacent numerals indicate central pressure.

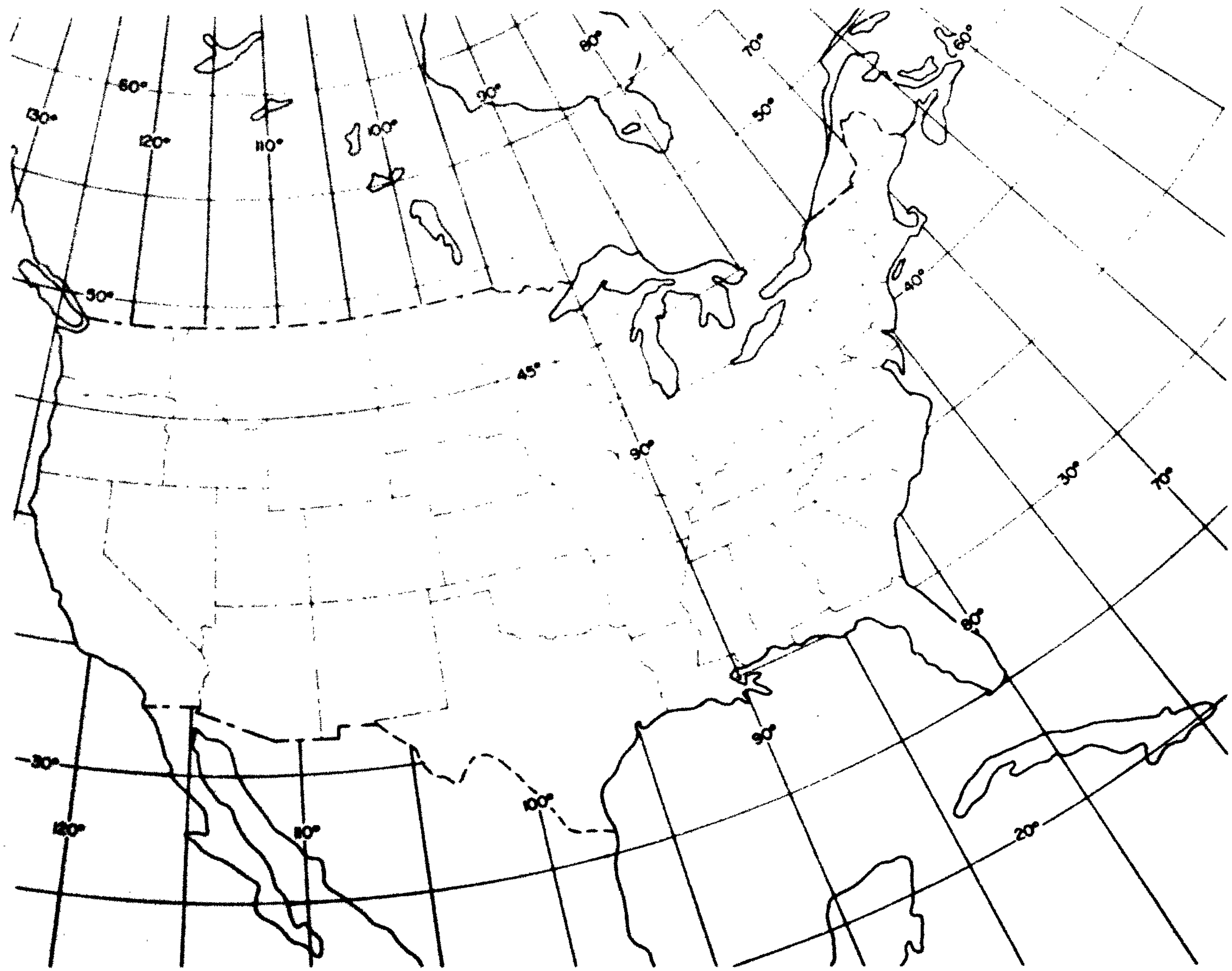

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TABLE 8-1
VERIFICATION SUMMARY OF CYCLONE SHOWN IN FIG. 8-1

Forecast interval, hr	Position-vector error, naut mi			Central-pressure error,* mb		
	Base tech	Modified tech	Surface data only	Base tech	Modified tech	Surface data only
12	12	12	36	+3	+3	+1
24	180	156	192	+1	+1	-3
36	42	60	-	+15	+15	-

*Central-pressure error equals predicted minus observed.

TABLE 8-2
VERIFICATION SUMMARY OF CYCLONE SHOWN IN FIG. 8-2

Forecast interval, hr	Position-vector error, naut mi			Central-pressure error,* mb		
	Base tech	Modified tech	Surface data only	Base tech	Modified tech	Surface data only
12	84	84	168	+3	+3	0
24	252	360	432	+9	+9	+9
36	468	360	-	+19	+19	-

*Central-pressure error equals predicted minus observed.

TABLE 8-3
VERIFICATION SUMMARY OF CYCLONE SHOWN IN FIG. 8-3

Forecast interval, hr	Position-vector error, naut mi			Central-pressure error,* mb		
	Base tech	Modified tech	Surface data only	Base tech	Modified tech	Surface data only
12	54	-	102	+9	-	+7
24	60	-	102	+7	-	+5
36	138	-	-	+3	-	-

*Central-pressure error equals predicted minus observed.

TABLE 8-4
VERIFICATION SUMMARY OF CYCLONE SHOWN IN FIG. 8-4

Forecast interval, hr	Position-vector error, naut mi			Central-pressure error,* mb		
	Base tech	Modified tech	Surface data only	Base tech	Modified tech	Surface data only
12	132	-	48	+10	-	+9
24	115	-	30	+8	-	+6
36	24	-	-	+3	-	-

*Central-pressure error equals predicted minus observed.

TABLE 8-5
VERIFICATION SUMMARY OF CYCLONE SHOWN IN FIG. 8-5

Forecast interval, hr	Position-vector error, naut mi			Central-pressure error,* mb		
	Base tech	Modified tech	Surface data only	Base tech	Modified tech	Surface data only
12	126	144	108	-2	-2	-3
24	360	360	360	-7	-7	-10
36	768	768	-	-8	-8	-

*Central-pressure error equals predicted minus observed.

TABLE 8-6
VERIFICATION SUMMARY OF CYCLONE SHOWN IN FIG. 8-6

Forecast interval, hr	Position-vector error, naut mi			Central-pressure error,* mb		
	Base tech	Modified tech	Surface data only	Base tech	Modified tech	Surface data only
12	144	156	180	-1	-1	+1
24	192	192	228	0	0	+3
36	156	156	-	+5	+5	-

*Central-pressure error equals predicted minus observed.

9.0 SUMMARY AND CONCLUSIONS

Equations for the prediction of 12-, 24-, and 36-hr displacements and changes in central pressure have been derived for North American cyclones. The equations remained stable when applied to an independent data sample. Comparisons with NWAC forecasts for the winter of 1962-1963 indicate that the equations yield competitive results. Equations applicable to the entire area considered in North America produced results that were in general at least as good as equations derived for subdivisions (zones) of the area.

Equations were derived from surface data only, for application whenever upper-air data are not available. Only a small decrease in accuracy was noted when the results of these equations were compared with those derived from both surface and upper-air data.

Application of the equations is completely objective, and they can be adapted for use at a weather station* or at a completely automated weather central.

A useful by-product of the data processing required for the research is a 5-yr sample of error-checked hemispheric gridpoint values of surface pressure and 500-mb heights filed in a form suitable for direct electronic data-processing machine analysis.

The developmental sample used in the regression analysis was derived from a series of computerized objective techniques. This is in contrast to the earlier study [14], in which the data were extracted and tabulated manually. Comparison of results indicates that the automated procedures, besides being expeditious, apparently suffered no information loss from interpolation errors.

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*See Appendix C for worksheets illustrating manual application.

10.0 RECOMMENDATIONS

Although the primary concern in these studies has been the behavior of the cyclone itself, there exists a need to incorporate the information contained in such a circulation forecast into a weather forecast. Even a perfect forecast of sea-level pressure is of little practical value if there is no means by which the weather (cloudiness, precipitation, wind, temperature, etc.) can be predicted or inferred. More emphasis, therefore, should be given to specifying weather from circulation forecasts to yield more useful predictive information.

The use of the methods described in this study yields information about the sea-level pressure at widely scattered locations. A more complete depiction of the surface circulation pattern would be desirable. One possible way to acquire a complete mapping of the pressure field is to employ existing statistical and dynamical methods to forecast the entire pressure field and modify them with the regression predictions of cyclones and other significant features such as anticyclones. Such a modification could be accomplished by methods similar to those used in objective analysis techniques.

Thus far, the moving-coordinate experiments have used only initial- and lagged-time data. The incorporation of mid-tropospheric circulation prognoses by numerical weather-prediction methods as possible predictors in the statistical analysis appears to have a reasonable chance for improving the results presented in this study and should be attempted.

The technique described in this study should not be limited to extrema in the sea-level pressure pattern. Other "significant features," such as 500-mb vorticity centers or height-change centers, can be used as predictands.

11.0 ACKNOWLEDGMENTS

The authors wish to express their appreciation to Mr. Paul MacDonald and Misses Dorothy Kapinos and Sally-Anne Lyons for their assistance in data tabulation and error checking; to Mr. Joseph Sekorski, who conducted the regression-vs-NWAC prognoses comparison; and to Mrs. Joline Blais, who typed the manuscript.

Excellent programming support was provided by Messrs. Steven Morrison and Charles Pike of the United Aircraft Corporation, who wrote most of the necessary computer programs used in this study. Other important programming contributions were made by Messrs. Frank Rodante, Russell Harris, and Isadore Enger, all of TRC.

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APPENDIX A. DATA PROCESSING*

One of the major problems encountered when undertaking a statistical problem of the nature described in this report concerns the data to be used in the investigation. When the scope of the problem reaches the point at which some 11,000,000 gridpoint values are extracted manually from analyzed maps, tabulated, and placed on punched cards, errors will persist despite the most careful and systematic error-checking procedures. The best that can be hoped for is a minimization of "gross" errors. Although the data received for this project had already undergone considerable checks for errors, it was felt necessary to devise additional automatic error-checking procedures and subject the data to them. Although only a small percentage of additional errors were detected, enough were found to make the procedures extremely worth while.

There were two basic data types used in the development of multiple linear-regression prediction equations for cyclone displacement and intensification over North America. Basically, these are historical series of weather maps (predictor data) and summaries of cyclone tracks (predictand data).

A.1 Predictor Data

The basic predictor data are a collection of gridpoint data made at the National Weather Records Center (NWRC) at Asheville, N.C. Pressure-height and temperature at several levels (including surface, 700 mb, and 500 mb) over the Northern Hemisphere were read from weather charts analyzed by the National Weather Analysis Center (NWAC) on a modified JNWP grid of 1020 points. Each map was actually read twice to eliminate errors. These gridpoint values were tabulated, placed on punched cards, and finally on IBM 705 magnetic tapes. The final set of data covered a continuous period of twice-daily (0000- and 1200-GCT) analyses from April 1955 through March 1960, a complete 5-yr sample. For the three fields of interest in significant-feature studies (sea-level pressure, 700-mb height, and 500-mb height), this involved more than 11,000,000 numbers. A detailed description of the gridpoint data-extraction procedures and card-tape formats is given in the Reference Manual for Climatic Data Computer Tapes [11].

A.2 Predictand Data

Cyclone tracks were tabulated from microfilmed NWAC surface analyses. The location (latitude and longitude) and central pressure of every winter (November–March) cyclone over North America (as defined in Fig. 2-1) were plotted at

*Most of the data preprocessing was cosponsored by the United States Air Force, under Contract AF19(626)-16, and the Federal Aviation Agency, under Contract FAA/BRD-363.

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6-hr intervals for the five winters corresponding to the gridpoint data. This included cyclones that were either previously or subsequently outside the area. Similar procedures were used for summer (May–September) cyclones. From these plotted tracks, only cyclones that were identifiable for 36 hr (24 hr for summer) were tabulated and put on punched cards. For those that qualified, the following information was tabulated for each synoptic time (0000 or 1200 GCT).

(a) Date and time.
(b) Latitude, longitude, and central pressure (initial time t_0).
(c) Latitude, longitude, and central pressure (t_0 + 12 hr).
(d) Latitude, longitude, and central pressure (t_0 + 24 hr).
(e) Latitude, longitude, and central pressure (t_0 + 36 hr).
(f) Latitude, longitude, and central pressure (t_0 - 6 hr).

The number of cases shown in Table 2-1 is equivalent to the number of cards that were punched.

With the IBM 705 magnetic tapes and the punched cards of cyclone tracks available for processing, a variety of computer programs (Table A-1) was written at the United Aircraft Corporation Research Laboratory. These programs and their sequential use are shown in the flow diagram, Fig. A-1. In detail, the programs were used as follows.

The first step was to process each of the Asheville IBM 705 grid tapes separately by the gridpoint data-conversion and -editing program. Since each tape contained only 2 mo of grid data, 30 tapes were enough to cover the full 60-mo (5-yr) period. This program selects the variables to be processed: sea-level pressure, 700-mb height, and 500-mb height. Other variables on the tapes, such as heights at other levels (e.g., 300 mb) and temperatures at any level, were not processed. Having made this selection, the program then examined every "map" (1020 gridpoints covering the Northern Hemisphere) for gross errors. Differences in values between adjacent gridpoints were computed, and a preselected percentage of the largest differences were printed out, along with appropriate identification. Also, gridpoints with missing data and values outside certain specified limits were noted and printed out. This program also converted the selected data and output it onto magnetic tape in a format acceptable to the kind of computer to be used for subsequent stages of processing (the IBM 7090). The output of this program was a set of three 7090 tapes for every one that was used as input, each of which contained only information from one level (surface, 700-mb, or 500-mb) for a 2-mo period. Thus, the processing of the thirty IBM 705 tapes resulted in ninety IBM 7090 tapes.

The next step was very important and was strictly a manual operation. It consisted of examining the printout of missing and otherwise suspicious gridpoint data. Many of the data, though printed out, were acceptable due to unusually strong gradients or intense systems. For example, all sea-level pressures in excess of

TABLE A-1
COMPUTER PROGRAMS
WRITTEN BY
UNITED AIRCRAFT CORPORATION RESEARCH LABORATORY

Program	Function
Gridpoint data conversion and editing	Selects gridpoint data of interest. Checks for gross errors. Converts 705 tape to 7090 tape.
Grid correction	Inserts corrections. Outputs merged tape.
Gridpoint interpolation	Converts from 433L grid to JNWP grid. Outputs merged tape.
Predictand preprocessor	Converts locations and central pressure to predictand format. Outputs on tape.
Significant-feature preprocessor	Generates a tape for screening regression by (a) selecting maps, (b) reading maps (transforming and interpolating grids), (c) deriving predictors.

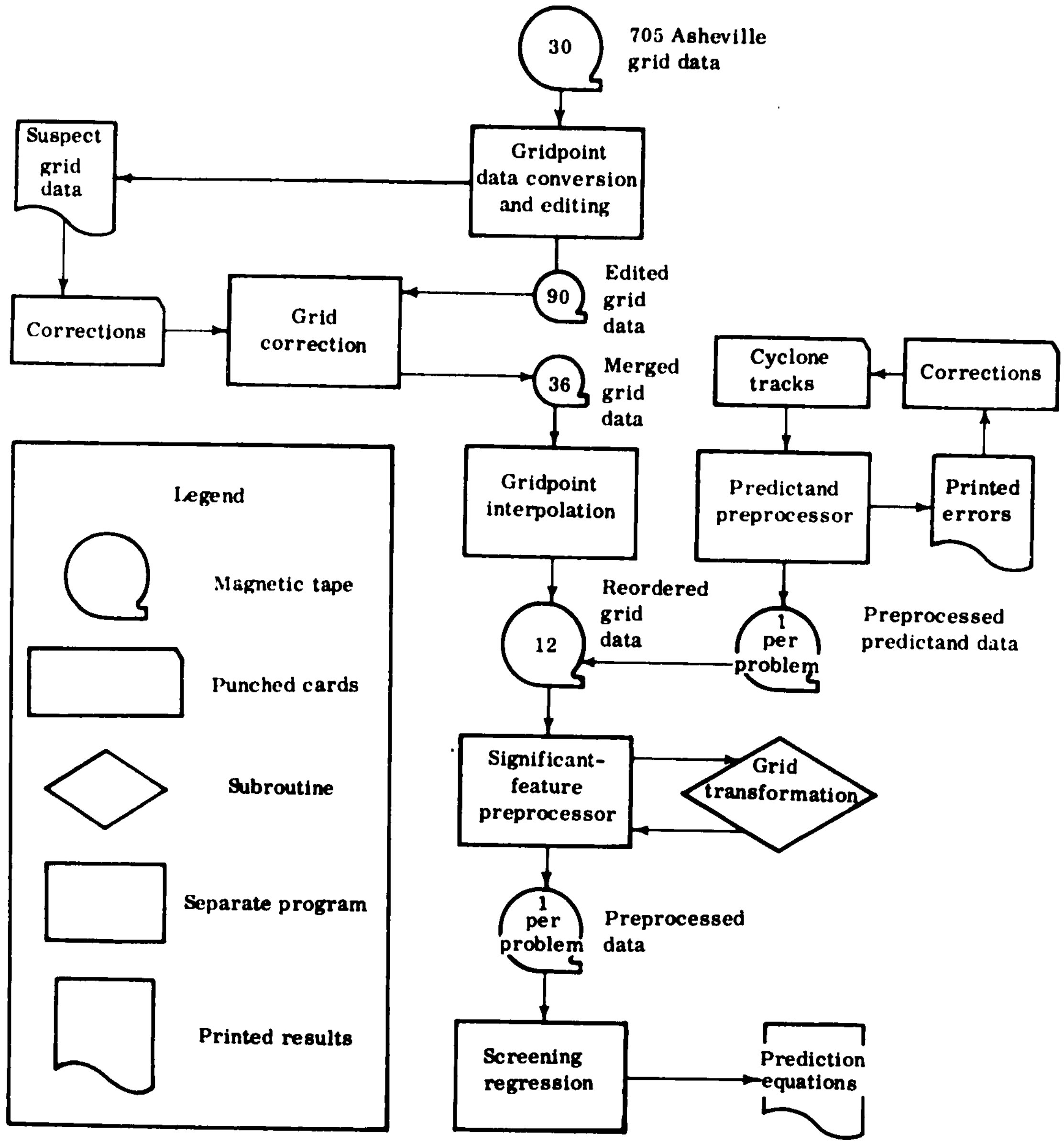

Fig. A-1. Computer programs used to preprocess data for use in screening regression. Numbers appearing within tape symbols refer to the number of magnetic tapes involved.

1060 mb were printed out. Many of these were valid because of the Siberian High, for instance. However, there were some pressures between 1090 and 1099 mb that were actually supposed to have been between 990 and 999 mb, as shown by examination of microfilm maps. The practice then was to go from the printout to NWAC microfilmed analyses to verify the validity of suspicious data. In this way, gross errors were noted, and corrected values were tabulated. Corrections to missing data were also supplied from examination of microfilmed maps. It should be emphasized that the grid data received from NWRC were, on the whole, in very good condition, with the error percentage being extremely small; however, the nature of the study required even additional scrutiny of the data to eliminate so-called gross errors.

The gridpoint corrections, having been tabulated, were placed on punched cards to be used as input to the grid-correction program. All correction cards for one level for 5 yr of one month were processed together (e.g., 500-mb heights for five Januaries). The program inserted the corrections in the proper places and wrote a new tape consisting of the one level for 5 yr of one month. Thus the program not only inserted the necessary corrections but also reduced the number of required tapes from 90 to 36.

The grid format used for the initial data extraction at NWRC was a modified JNWP grid, in which data were read for every other JNWP gridpoint. It was found desirable to have data at every JNWP gridpoint to facilitate subsequent computations. The grid-interpolation program accomplished this by computing values at the in-between gridpoints by a least-squares fitting of a quadratic surface, using surrounding data at known gridpoints. Thus, the program output complete maps on the 1977-point JNWP grid. Another feature of the program is that it used three tapes as input (e.g., five Januaries of sea-level pressure, 700-mb height, and 500-mb height). It read in the first record (map) from each tape, which were all for the same time (e.g., 0000 GCT 1 Jan. 1956), and output them as the first three records of the new tape. Hence, the final tape for a month was in chronological order (i.e., three levels for 0000 GCT 1 Jan. 1956, three levels for 1200 GCT 1 Jan. 1956, three levels for 0000 GCT 2 Jan. 1956, etc., through 31 Jan. 1960). The result was that data on the 36 tapes using a modified JNWP grid were now contained on 12 tapes with a full JNWP grid, each tape representing a complete 5-yr month. These tapes were then ready to serve as the basic set of "maps" for predictor information.

The predictand data were handled independently of these programs. The predictand-preprocessor program accepted the punched-card input of significant-feature tracks and computed the two components of displacement and the change in central pressure, which were the predictand forms desired. This information was then placed on magnetic tape. An important by-product of this program is a printout of displacements and changes in central pressure that deviate considerably from climatology. Thus, an error-checking procedure was provided, and new punched cards were prepared when errors were noted.

The predictand tape and the predictor tapes were then used as input to the significant-features preprocessor program. This program generated a tape for screening regression by selecting cyclones, "reading" maps, and deriving predictors: the first cyclone case was determined from the cyclone-tabulation input. Using the time and date of this case, the gridpoint-data tapes were searched to find the three data records corresponding to this time (one record for each map of sea-level pressure, 700-mb height, and 500-mb height) and also for the same three maps 12 hr previous to that time. These six records were read into the machine. The next step was analogous to superimposing a moving-coordinate grid (centered with respect to the cyclone) over the fixed-grid system and interpolating data values for gridpoints in the moving-coordinate system. The subroutine that computed these locations is the grid-transformation routine. Whereas the JNWP or "fixed" grid has 1977 gridpoints, the moving grid has only 221 points. With the use of data at the four surrounding gridpoints of the fixed grid, values were computed by interpolation at each of the 221 gridpoints of the moving-grid system for all six maps stored in the machine. The procedure of reading maps into the machine, computing locations of gridpoints, and interpolating data was accomplished for all cyclones to be considered. Selection and derivation of possible predictors from this newly generated set of data was then performed. Possible predictors consisted of point values of sea-level pressure, 500-mb height, 1000–500-mb thickness, and 12-hr changes of these quantities. The changes in latitude and longitude (both in degrees of latitude) and central pressure of the cyclone were used as predictands for 12, 24, and 36 hr.

The result of this series of programs was magnetic tapes that could be used directly as input to the screening-regression program to derive prediction equations for cyclones over North America as well as cyclones in Europe and Asia and anticyclones in Europe. In addition, useful by-products include a relatively error-free 5-yr set of gridpoint data, which can be used for work on other significant features, such as North American anticyclones, or for other meteorological problems.

APPENDIX B. PREDICTION EQUATIONS

The prediction equations derived from the regression analysis have the form

$$\hat{Y} = A_0 + A_1X_1 + A_2X_2 + \cdots + A_nX_n, \tag{B-1}$$

where $\hat{Y}$ is the predictand, the A's are constant coefficients derived (by the method of least squares) from the developmental sample, and the X's are the predictors selected by the screening procedure.

Each set of prediction equations consists of three, six, or nine equations (depending on the number of forecast intervals): the three predictands of northward displacement, eastward displacement, and change in central pressure for the forecast intervals of 12, 24, and/or 36 hr.

The pair of numbers that is associated with a given predictor in the equations refers to the grid location in the (k,ℓ)-grid system of Fig. 3-1. The symbols used are defined in Tables 3-1 and 3-2.

For operational application, the equations in worksheet form represent a more convenient means for solution. An example of such worksheets is shown in Appendix C.

B.1 Winter Cyclones

B.1.1 Equations Using Both Surface and Upper-air Predictors, without Past History

B.1.1.1 Northwestern Zone

$$\hat{N}_{12} = -47.1023 + 0.0453\,Z(13,5) - 0.0313\,Z(9,7) - 0.1212\,\Delta P(11,7) - 0.0716\,\lambda$$
$$- 0.0193\,H(5,5) - 0.0829\,\Delta P(5,5) + 0.0605\,P(11,3)$$

$$\hat{E}_{12} = -1.1129 + 0.0195\,Z(11,9) - 0.0240\,Z(11,1) - 0.0321\,\Delta Z(9,1) + 0.0962\,P(11,5)$$
$$- 0.0876\,P(11,1)$$

$$\hat{D}_{12} = +159.2940 + 0.1743\,\Delta P(7,7) + 0.1428\,\Delta Z(9,5) - 0.5859\,P(10,5) + 0.4252\,P(11,5)$$

$$\hat{N}_{24} = -11.1848 + 0.0814\,Z(13,5) - 0.0675\,Z(9,7) - 0.1641\,\lambda - 0.0464\,\Delta Z(5,5)$$

$$\hat{E}_{24} = -22.9553 + 0.0414\,Z(11,9) - 0.0441\,Z(11,1) - 0.0728\,\Delta Z(9,3) + 0.1505\,P(11,5)$$
$$- 0.1244\,P(13,1)$$

$$\hat{D}_{24} = +377.937 - 0.8665\,P(10,5) + 0.1752\,\Delta Z(9,5) + 0.4893\,P(11,5) + 0.1347\,\Delta Z(9,7)$$

$$\hat{N}_{36} = +17.4888 - 0.0184\,H(13,5) - 0.0018\,H(7,7) - 0.2408\,\lambda + 0.0144\,Z(13,3) - 0.0914\,Z(9,7) + 0.0977\,Z(13,5)$$

$$\hat{E}_{36} = 16.1877 + 0.0580\,Z(11,9) - 0.0614\,Z(11,1) - 0.0881\,\Delta Z(9,3) + 0.1981\,P(11,5) - 0.1783\,P(13,1)$$

$$\hat{D}_{36} = +708.0190 - 0.5894\,P(10,5) + 0.1555\,\Delta Z(9,5) - 0.0614\,Z(15,1) + 0.1896\,\Delta Z(9,7)$$

B.1.1.2 Northeastern Zone

$$\hat{N}_{12} = -12.6527 + 0.0143\,Z(15,5) - 0.0122\,Z(7,7) + 0.0312\,Z(13,7) - 0.0261\,Z(9,7)$$

$$\hat{E}_{12} = +50.1402 + 0.0327\,Z(11,9) - 0.1557\,\Delta P(7,5) + 0.0394\,\Delta Z(11,7) - 0.0585\,P(15,3) - 0.0148\,H(7,7) - 0.0143\,Z(11,11)$$

$$\hat{D}_{12} = +151.043 + 0.0868\,\Delta Z(9,3) + 0.0606\,\Delta Z(9,9) - 0.2518\,P(10,5) + 0.2036\,P(9,7) - 0.0786\,\Delta Z(5,3) - 0.0588\,\Delta Z(15,11) - 0.1039\,P(15,3)$$

$$\hat{N}_{24} = -30.3683 + 0.0221\,Z(15,5) - 0.0461\,Z(7,7) + 0.0421\,Z(15,7)$$

$$\hat{E}_{24} = +97.3384 + 0.0434\,Z(11,9) - 0.1746\,P(13,1)$$

$$\hat{D}_{24} = +247.705 + 0.0695\,Z(9,7) - 0.1526\,\Delta Z(5,5) + 0.1287\,\Delta Z(9,9) - 0.4580\,P(10,5) - 0.0837\,H(13,3) + 0.1158\,P(15,9) + 0.0671\,Z(7,1) + 0.4033\,\Delta P(11,3)$$

$$\hat{N}_{36} = -41.6853 + 0.0350\,Z(15,5) - 0.0679\,Z(9,7) + 0.0566\,Z(15,7) - 0.0553\,\Delta H(9,1)$$

$$\hat{E}_{36} = +210.873 + 0.0497\,Z(13,9) - 0.2578\,P(13,1) - 0.2620\,\Delta P(7,5) - 0.0246\,H(5,9)$$

$$\hat{D}_{36} = +16.9963 + 0.1024\,H(9,7) - 0.1982\,\Delta Z(5,5) + 0.2111\,\Delta Z(9,9) + 0.2357\,P(15,9) - 0.0854\,Z(13,3) - 0.2727\,P(10,5)$$

B.1.1.3 Southwestern Zone

$$\hat{N}_{12} = +163.681 + 0.1120\,Z(13,3) - 0.1110\,\lambda - 0.0095\,Z(7,7) + 0.0164\,Z(15,7) - 0.0935\,H(13,3) - 0.2717\,P(11,5) - 0.1071\,\Delta P(9,7) + 0.0418\,P(3,9) + 0.2148\,P(11,3) - 0.1866\,P(13,1)$$

$$\hat{E}_{12} = -7.9962 + 0.0279\,Z(9,9) - 0.2068\,\Delta P(7,5) - 0.0248\,H(7,5)$$

$$\hat{D}_{12} = +186.553 + 0.4135\,\Delta P(9,7) - 0.1850\,P(5,5)$$

$$\hat{N}_{24} = -9.6529 + 0.0298\,Z(13,3) - 0.1262\,\lambda - 0.0517\,Z(9,7) + 0.0270\,H(13,9) + 0.0289\,P(15,3) - 0.1503\,P(3,3) - 0.1432\,\Delta P(9,7) + 0.0360\,Z(15,5) - 0.1889\,P(11,5) + 0.2569\,P(13,3)$$

$$\hat{E}_{24} = + 18.0638 + 0.0130\,Z(9,11) - 0.3554\,\Delta P(7,5) - 0.0452\,H(7,5) + 0.0636\,Z(11,7)$$
$$+ 0.2779\,\Delta P(13,5) - 0.0426\,Z(13,3)$$

$$\hat{D}_{24} = + 202.759 + 0.4996\,\Delta P(9,7) - 0.0931\,Z(11,1) + 0.0686\,H(9,7) - 0.5119\,P(10,5)$$
$$+ 0.3596\,P(11,7) + 0.1030\,\Delta H(7,3)$$

$$\hat{N}_{36} = + 103.349 + 0.1086\,Z(15,3) - 0.2766\,\lambda - 0.0557\,Z(7,7) - 0.1747\,P(11,9)$$

$$\hat{E}_{36} = - 40.0025 + 0.0634\,Z(9,11) - 0.4060\,\Delta P(7,5) - 0.0451\,H(7,5)$$

$$\hat{D}_{36} = + 528.061 - 0.1749\,Z(11,1) + 0.0770\,Z(9,11) - 0.3320\,P(10,5)$$

B.1.1.4 Southeastern Zone

$$\hat{N}_{12} = + 42.5547 - 0.0608\,P(9,9) + 0.0138\,Z(13,5) - 0.0180\,Z(7,7) - 0.1205\,\Delta P(9,5)$$
$$+ 0.0153\,Z(13,7)$$

$$\hat{E}_{12} = - 48.1421 + 0.0312\,Z(11,9) - 0.0356\,Z(7,3) - 0.1361\,\Delta P(7,3) + 0.0547\,P(13,7)$$

$$\hat{D}_{12} = + 29.7512 + 0.4539\,\Delta P(9,3) + 0.1099\,\Delta Z(9,5) - 0.0467\,Z(11,3) + 0.0320\,H(7,9)$$
$$+ 0.2358\,\Delta P(7,5)$$

$$\hat{N}_{24} = + 85.2001 - 0.1092\,P(9,9) + 0.0269\,Z(15,5) - 0.0212\,Z(7,7) - 0.2088\,\Delta P(9,5)$$
$$+ 0.0268\,Z(15,7) - 0.0185\,H(7,9)$$

$$\hat{E}_{24} = - 103.031 - 0.0011\,Z(13,11) - 0.0601\,Z(9,1) + 0.1594\,P(13,7) + 0.0455\,Z(11,9)$$
$$- 0.0374\,Z(7,5) + 0.0210\,Z(15,11) - 0.0505\,\Delta Z(5,3)$$

$$\hat{D}_{24} = + 174.012 + 0.6361\,\Delta P(9,3) - 0.1564\,Z(11,1) + 0.0620\,H(7,9) + 0.1022\,\Delta Z(9,9)$$
$$- 0.3513\,P(5,5) + 0.3555\,P(13,1) + 0.0691\,\Delta Z(11,7) + 0.5116\,\Delta P(9,5)$$
$$- 0.3279\,P(10,5) + 0.3313\,P(11,7)$$

$$\hat{N}_{36} = + 118.502 - 0.0443\,Z(7,9) + 0.0591\,Z(15,7) - 0.2073\,\Delta P(9,5) - 0.1399\,P(11,9)$$
$$- 0.0574\,\Delta Z(7,5)$$

$$\hat{E}_{36} = - 124.854 - 0.0551\,Z(9,1) + 0.0799\,Z(13,9) - 0.0779\,Z(7,5) + 0.2308\,P(11,7)$$
$$- 0.0822\,Z(13,1) + 0.0738\,Z(3,1)$$

$$\hat{D}_{36} = + 413.088 + 0.9645\,\Delta P(9,3) - 0.1444\,Z(9,1) + 0.2311\,\Delta H(9,9) + 0.0670\,Z(9,9)$$
$$- 0.2665\,P(10,5)$$

B.1.1.5 All Zones

$$\hat{N}_{12} = + 83.5783 - 0.0428\lambda + 0.0535\,Z(13,5) - 0.0286\,Z(9,7) - 0.0279\,\Delta P(11,7)$$
$$+ 0.0836\,\Delta P(9,3) - 0.0217\,H(13,3) - 0.0971\,P(11,7) - 0.1190\,\Delta P(9,7)$$
$$- 0.0467\,P(5,1) + 0.0583\,P(9,7)$$

$$\hat{E}_{12} = + 6.5083 + 0.0134\,Z(11,9) - 0.0055\,Z(9,1) - 0.1189\,\Delta P(7,5) - 0.0154\,\Delta Z(7,3)$$
$$+ 0.0282\,\Delta Z(11,7) - 0.0226\,H(9,3) + 0.0314\,P(13,7) - 0.0380\,P(15,3)$$
$$+ 0.0254\,P(5,7) - 0.1075\,P(9,3) + 0.0927\,P(11,5) + 0.0197\,H(9,7)$$
$$- 0.0117\,H(7,7) - 0.0157\,\Delta H(9,5)$$

$$\hat{D}_{12} = + 272.183 + 0.3942\,\Delta P(9,5) + 0.0590\lambda - 0.5929\,P(10,5) + 0.0550\,\Delta H(9,5)$$
$$+ 0.4357\,P(11,5) - 0.0327\,H(11,1) + 0.0308\,Z(9,9) - 0.0942\,P(5,5)$$
$$+ 0.1863\,\Delta P(9,7) + 0.0459\,\Delta Z(9,3) - 0.0118\,Z(13,9)$$

$$\hat{N}_{24} = + 20.5766 - 0.0787\lambda + 0.0145\,Z(15,5) + 0.0108\,Z(7,7) - 0.0971\,\Delta P(11,7)$$
$$+ 0.0269\,\Delta Z(13,3) - 0.0684\,Z(9,7) + 0.0263\,Z(13,7) - 0.0428\,\Delta Z(7,7)$$
$$+ 0.0362\,Z(13,5) + 0.1026\,\Delta P(9,3) - 0.0493\,P(11,9)$$

$$\hat{E}_{24} = + 10.1768 + 0.0317\,Z(11,9) + 0.0006\,Z(9,1) - 0.0404\,\Delta Z(7,3) + 0.0914\,P(13,7)$$
$$- 0.0638\,Z(11,3) + 0.0348\,\Delta Z(11,7) - 0.1322\,\Delta P(7,5) - 0.0240\,H(7,5)$$
$$+ 0.0326\,Z(11,5) + 0.0093\,Z(15,11) - 0.0800\,P(13,1)$$

$$\hat{D}_{24} = + 706.947 + 0.1081\,Z(11,1) + 0.1529\lambda + 0.1477\,\Delta Z(9,9) + 0.1124\,\Delta P(9,3)$$
$$+ 0.0935\,H(9,7) - 0.8755\,P(10,5) + 0.0892\,\Delta Z(9,5) + 0.3488\,P(11,5)$$
$$+ 0.3652\,\Delta P(9,5) - 0.0738\,H(11,5) - 0.1647\,P(5,5)$$

$$\hat{N}_{36} = - 9.6302 - 0.1206\lambda + 0.0088\,Z(15,5) - 0.0676\,Z(9,7) + 0.0607\,Z(13,5)$$
$$- 0.2193\,P(11,7) - 0.0575\,\Delta Z(7,7) + 0.0619\,P(15,7) + 0.1368\,P(9,7)$$
$$+ 0.0203\,Z(15,7) + 0.0369\,\Delta H(11,5)$$

$$\hat{E}_{36} = - 47.2610 - 0.0091\,Z(13,11) - 0.0234\,Z(9,1) + 0.0504\,Z(11,9) - 0.0579\,\Delta Z(7,5)$$
$$+ 0.1756\,P(13,7) - 0.0406\,Z(11,3) + 0.0266\,Z(15,11) - 0.0241\,H(7,5)$$
$$- 0.1783\,P(13,1) + 0.1276\,\Delta P(13,5) + 0.0807\,P(3,3)$$

$$\hat{D}_{36} = + 523.605 + 0.0041\,Z(11,1) + 0.1900\lambda + 0.0596\,Z(9,9) - 0.7045\,P(10,5)$$
$$+ 0.1200\,\Delta Z(9,9) + 0.3786\,P(13,7) + 0.0952\,\Delta Z(9,5) - 0.1014\,Z(13,3)$$
$$- 0.0909\,\Delta H(11,5) - 0.1426\,P(5,7) + 0.2990\,\Delta P(11,7) - 0.3200\,\Delta P(3,3)$$

B.1.2 Equations Using Both Surface and Upper-air Predictors, with Past History

B.1.2.1 Northwestern Zone

$$\hat{N}_{12} = -6.2902 + 0.7725\,\Delta\phi + 0.0121\,\Delta H(13,5) + 0.0258\,Z(13,5) - 0.0198\,Z(9,7) - 0.0576\,\lambda$$

$$\hat{E}_{12} = +0.2824 + 0.4702\,\Delta\lambda + 0.0169\,Z(11,9) - 0.0175\,Z(13,1)$$

$$\hat{D}_{12} = +173.68 + 0.0663\,\Delta Z(9,7) - 0.6792\,P(10,5) + 0.1297\,\Delta Z(9,5) + 0.5046\,P(11,5)$$

$$\hat{N}_{24} = -0.0391 + 0.6192\,\Delta\phi + 0.0369\,\Delta H(13,5) - 0.1532\,\lambda + 0.0069\,Z(15,3) - 0.1764\,\Delta P(13,9) - 0.0495\,Z(9,7) + 0.0495\,Z(13,5)$$

$$\hat{E}_{24} = -60.922 + 0.0343\,Z(11,9) - 0.0559\,Z(11,1) - 0.0480\,\Delta Z(9,11) + 0.0953\,P(13,7) - 0.0460\,\Delta Z(9,3)$$

$$\hat{D}_{24} = +347.70 + 0.1408\,\Delta Z(9,7) - 0.9372\,P(10,5) + 0.1534\,\Delta Z(9,5) + 0.5892\,P(11,5) + 0.5644\,\Delta P_c$$

$$\hat{N}_{36} = -5.4003 + 0.0638\,H(13,5) - 0.0615\,H(7,7)$$

$$\hat{E}_{36} = +15.569 + 0.0594\,Z(11,9) - 0.0696\,Z(11,1)$$

$$\hat{D}_{36} = +597.45 - 0.4771\,P(10,5) + 0.2653\,\Delta Z(9,7) - 0.0635\,Z(13,1)$$

B.1.2.2 Northeastern Zone

$$\hat{N}_{12} = -14.451 + 0.8871\,\Delta\phi + 0.0252\,Z(15,7) - 0.0168\,Z(9,7)$$

$$\hat{E}_{12} = -38.823 + 0.0213\,Z(11,9) - 0.1557\,\Delta P(7,5) + 0.0405\,\Delta Z(11,7)$$

$$\hat{D}_{12} = +34.909 + 0.1066\,\Delta Z(9,3) + 0.0705\,\Delta Z(9,9) - 0.2243\,P(10,5) + 0.1871\,P(9,7)$$

$$\hat{N}_{24} = -25.394 + 1.0913\,\Delta\phi + 0.0551\,Z(15,7) - 0.0402\,Z(9,7)$$

$$\hat{E}_{24} = +76.975 + 0.0348\,Z(11,9) - 0.0269\,Z(11,1) + 0.0295\,Z(13,7) - 0.0466\,\Delta Z(7,5) - 0.0240\,H(7,9) - 0.1027\,P(15,3)$$

$$\hat{D}_{24} = +67.160 + 0.0748\,Z(9,7) - 0.1837\,\Delta Z(5,5) + 0.1834\,\Delta Z(9,9) - 0.1963\,P(10,5)$$

$$\hat{N}_{36} = -55.825 + 0.0400\,Z(15,5) - 0.0717\,Z(9,7) + 0.0636\,Z(15,7)$$

$$\hat{E}_{36} = +166.38 + 0.0577\,Z(13,9) - 0.2698\,P(13,1)$$

$$\hat{D}_{36} = +78.475 + 0.0979\,H(9,7) - 0.1847\,\Delta Z(5,5) + 0.1335\,\Delta Z(9,9) + 0.2659\,P(15,9) - 0.1472\,Z(13,3) - 0.8691\,P(10,5) + 0.0868\,Z(9,3) + 0.4643\,P(11,7) + 0.5406\,\Delta P(9,5)$$

B.1.2.3 Southwestern Zone

$$\hat{N}_{12} = -\ 40.884 + 0.8347\,\Delta\phi + 0.0257\,Z(15,5) - 0.0728\,\lambda - 0.4314\,\Delta\lambda$$

$$\hat{E}_{12} = -\ 7.0987 + 1.0112\,\Delta\lambda + 0.0257\,Z(11,7) - 0.0225\,Z(7,5) - 0.1399\,\Delta P(7,3)$$

$$\hat{D}_{12} = +\ 197.03 + 0.3937\,\Delta P(9,7) - 0.1951\,P(5,5)$$

$$\hat{N}_{24} = +\ 83.301 + 0.0875\,Z(13,3) - 0.1685\,P(11,7) + 0.7803\,\Delta\phi - 0.1493\,\lambda - 0.0340\,Z(9,7)$$

$$\hat{E}_{24} = -52.840 + 1.5444\,\Delta\lambda + 0.0275\,Z(11,11) - 0.0671\,\Delta Z(7,3) - 0.1696\,\Delta P(11,9)$$

$$\hat{D}_{24} = +\ 308.01 - 1.7539\,\Delta\phi + 0.0319\,Z(9,11) - 0.9873\,P(10,5) + 0.1508\,\Delta Z(9,5)$$
$$+\ 0.6211\,P(11,5) - 0.1336\,\Delta H(11,5)$$

$$\hat{N}_{36} = -\ 28.743 + 0.0763\,Z(15,5) - 0.0432\,Z(7,9) - 0.2483\,\lambda - 0.4141\,P(11,5)$$
$$+\ 0.3510\,P(13,3) + 0.0283\,Z(3,9)$$

$$\hat{E}_{36} = +\ 256.69 + 1.5141\,\Delta\lambda + 0.0142\,Z(11,11) - 0.0576\,\Delta Z(7,3) - 0.3116\,\Delta P(11,9)$$
$$-\ 0.0834\,\Delta H(13,3) - 0.0739\,Z(15,1) + 0.1331\,\Delta Z(11,7) + 0.0596\,Z(13,7)$$
$$-\ 0.3170\,P(11,1) + 0.4372\,\phi + 0.0272\,Z(5,11)$$

$$\hat{D}_{36} = +\ 361.14 + 0.0989\,Z(9,11) - 0.0782\,Z(11,3) - 0.3895\,P(10,5) - 1.6799\,P(11,5)$$

B.1.2.4 Southeastern Zone

$$\hat{N}_{12} = +\ 51.253 + 0.5136\,\Delta\phi - 0.1049\,\Delta P_c - 0.0618\,P(9,9) + 0.0189\,Z(15,5)$$
$$-\ 0.0128\,H(5,7) - 0.0727\,\Delta P(11,7)$$

$$\hat{E}_{12} = -\ 0.5478 + 0.5182\,\Delta\lambda + 0.0250\,Z(11,9) - 0.0248\,Z(7,3) - 0.0988\,\Delta P(7,3)$$
$$+\ 0.0304\,\Delta Z(11,7)$$

$$\hat{D}_{12} = +\ 58.190 + 0.4228\,\Delta P(9,3) + 0.0970\,\Delta Z(9,5) - 0.0531\,Z(11,3) + 0.0317\,H(7,9)$$
$$+\ 0.3154\,\Delta P(7,5) + 0.0471\,\Delta H(9,9) + 0.0782\,P(13,5) - 0.1614\,P(5,5)$$
$$-\ 0.8648\,\Delta\phi - 0.4314\,P(10,5) + 0.5014\,P(11,5)$$

$$\hat{N}_{24} = -\ 2.0672 + 1.2065\,\Delta\phi - 0.0375\,Z(9,9) + 0.0399\,H(13,7) - 0.0394\,\Delta Z(7,5)$$

$$\hat{E}_{24} = -\ 109.23 + 0.7675\,\Delta\lambda + 0.0156\,Z(13,11) - 0.0595\,Z(7,3) + 0.1301\,P(13,7)$$
$$+\ 0.0317\,Z(11,9) - 0.0526\,Z(15,1) + 0.0544\,\Delta Z(11,7) + 0.0520\,Z(3,1)$$

$$\hat{D}_{24} = +\ 313.43 + 0.6608\,\Delta P(9,3) - 0.1616\,Z(11,1) + 0.0555\,H(7,9) + 0.1216\,\Delta H(9,9)$$
$$-\ 0.3220\,P(5,5) + 0.3255\,\Delta P(11,9) + 0.1881\,P(13,1) + 0.5986\,\Delta P(9,5)$$
$$-\ 0.8641\,P(10,5) + 0.8879\,P(11,5)$$

$$\hat{N}_{36} = +115.72 - 0.0413\,Z(7,9) + 0.0571\,Z(15,7) - 0.2036\,\Delta P(10,5) - 0.0708\,\Delta Z(7,5) - 0.1397\,P(11,9)$$

$$\hat{E}_{36} = -85.596 + 1.1994\,\Delta\lambda - 0.0510\,Z(9,1) + 0.0658\,Z(13,9) - 0.0739\,Z(7,5) - 0.0799\,Z(15,1) + 0.1902\,P(11,7) + 0.0794\,Z(3,1)$$

$$\hat{D}_{36} = +393.97 + 0.7571\,\Delta P(9,3) - 0.0470\,Z(9,1) + 0.2290\,\Delta H(9,9) + 0.0689\,Z(9,9) - 0.6165\,P(10,5) - 0.0729\,H(13,5) - 0.1287\,\Delta Z(3,7) + 0.5942\,\Delta P(9,5) + 0.3111\,P(13,7)$$

B.1.2.5 All Zones

$$\hat{N}_{12} = -68.994 + 0.7884\,\Delta\phi + 0.0138\,Z(15,5) - 0.0266\,Z(9,7) + 0.0197\,H(11,7) + 0.0582\,P(13,3) - 0.0250\,\lambda$$

$$\hat{E}_{12} = -26.016 + 0.5644\,\Delta\lambda + 0.0184\,Z(11,9) - 0.0061\,Z(9,1) - 0.0132\,\Delta Z(7,3) + 0.0260\,\Delta Z(11,7) + 0.0870\,P(13,5) - 0.0582\,P(15,3) - 0.0144\,Z(9,3) - 0.0169\,\Delta Z(7,5)$$

$$\hat{D}_{12} = +101.86 + 0.3998\,\Delta P(9,5) + 0.0578\,\lambda - 0.0295\,Z(11,3) + 0.0422\,H(9,5) + 0.0514\,\Delta Z(9,9) + 0.0881\,\Delta Z(9,3) - 0.6841\,P(10,5) + 0.6152\,P(11,5) - 0.6082\,\Delta\phi - 0.0340\,H(7,1)$$

$$\hat{N}_{24} = -108.07 + 0.8390\,\Delta\phi + 0.0363\,Z(15,5) - 0.0574\,Z(9,7) + 0.0339\,H(11,7) - 0.0481\,\lambda + 0.0884\,P(13,3) - 0.0253\,\Delta Z(7,7)$$

$$\hat{E}_{24} = -125.19 + 0.7555\,\Delta\lambda + 0.0087\,Z(13,11) - 0.0074\,Z(9,1) + 0.0207\,Z(11,9) - 0.0553\,\Delta Z(7,3) + 0.1308\,P(13,7) - 0.0451\,Z(11,3) + 0.0479\,\Delta Z(11,7) + 0.0185\,H(13,7) - 0.0911\,\Delta P(9,9)$$

$$\hat{D}_{24} = +324.11 + 0.1419\,\lambda - 0.0658\,Z(11,3) + 0.0599\,Z(9,7) + 0.1114\,\Delta Z(9,9) - 1.3105\,P(10,5) + 0.5747\,\Delta P_c + 0.8568\,P(11,5) + 0.3902\,\Delta P(10,5) - 0.2232\,P(5,5) + 0.3506\,P(9,3) - 0.8131\,\Delta\phi$$

$$\hat{N}_{36} = -114.17 + 0.8173\,\Delta\phi + 0.0361\,Z(15,3) - 0.0300\,Z(9,9) + 0.0503\,H(13,7) - 0.0869\,\lambda - 0.0388\,Z(9,7) + 0.0891\,P(15,7) - 0.0426\,\Delta H(7,7)$$

$$\hat{E}_{36} = -\ 27.865 + 1.0232\,\Delta\lambda - 0.0043\,Z(13, 11) - 0.0359\,Z(9, 1) + 0.1710\,P(13, 7)$$
$$-\ 0.2020\,P(13, 1) - 0.0256\,H(7, 5) + 0.0195\,Z(5, 1) + 0.0319\,Z(11, 9) - 0.0242\,\Delta Z(7, 3)$$
$$+\ 0.0231\,Z(15, 11) - 0.0310\,Z(15, 1) - 0.0410\,\lambda + 0.0984\,P(3, 3) + 0.0574\,\Delta Z(11, 7)$$
$$-\ 0.1694\,\Delta P(9, 9) + 0.1183\,P(7, 9) - 0.1189\,P(9, 7)$$

$$\hat{D}_{36} = +\ 519.82 - 0.0530\,Z(11, 1) + 0.0251\,Z(9, 9) + 0.1879\,\lambda - 1.0954\,P(10, 5)$$
$$+\ 0.4614\,P(11, 7) + 0.6281\,\Delta P(10, 5) - 0.0824\,H(13, 3) - 0.1498\,P(5, 7)$$
$$+\ 0.1414\,\Delta Z(9, 9) + 0.0705\,H(9, 7) + 0.3240\,P(9, 3)$$

B.1.3 Equations Using Surface Predictors Only, without Past History (All Zones)*

$$\hat{N}_{12} = +\ 31.510 - 0.0646\,\lambda + 0.0686\,P(15, 7) - 0.0197\,P(10, 6) - 0.1428\,\Delta P(9, 7)$$
$$+\ 0.0881\,\Delta P(7, 3) - 0.1153\,P(11, 7) - 0.0635\,P(6, 2) + 0.1683\,P(13, 3) + 0.0938\,\Delta P(10, 2)$$
$$+\ 0.0752\,\Delta P(11, 9) + 0.0209\,P(3, 9) - 0.0839\,P(13, 1)$$

$$\hat{E}_{12} = -\ 0.9259 + 0.0297\,P(13, 11) - 0.0921\,\Delta P(7, 5) - 0.0327\,P(11, 1) + 0.0829\,P(6, 6)$$
$$+\ 0.0106\,P(13, 7) - 0.0347\,P(17, 3) - 0.2225\,P(9, 3) + 0.1426\,\Delta P(10, 4) + 0.0786\,P(7, 1)$$
$$+\ 0.1944\,P(13, 5) - 0.1091\,P(14, 4) - 0.0729\,\Delta P(8, 6) - 0.0614\,\Delta P(3, 5)$$

$$\hat{D}_{12} = +\ 185.54 + 0.0587\,\Delta P(9, 5) + 0.0845\,\lambda - 0.6215\,P(10, 5) + 0.5750\,P(11, 5)$$
$$-\ 0.1925\,\Delta P(5, 3) + 0.3847\,\Delta P(10, 4) + 0.1764\,\Delta P(10, 8) - 0.6411\,P(17, 5)$$
$$-\ 0.0840\,P(6, 6) + 0.1846\,\Delta P(8, 6)$$

$$\hat{N}_{24} = +\ 34.478 - 0.1274\,\lambda + 0.0424\,P(17, 7) + 0.0807\,P(10, 6) + 0.1222\,P(14, 4)$$
$$-\ 0.1517\,P(7, 1) + 0.1925\,\Delta P(7, 1) - 0.2163\,\Delta P(9, 7) - 0.2590\,P(11, 7) + 0.1480\,\Delta P(11, 9)$$
$$+\ 0.0534\,P(1, 7) + 0.0912\,P(15, 7)$$

$$\hat{E}_{24} = +\ 92.505 + 0.0678\,P(13, 11) - 0.1242\,P(13, 1) + 0.1995\,P(13, 7) - 0.0674\,\lambda + 0.1562\,\phi$$
$$-\ 0.1682\,\Delta P(7, 5) + 0.1053\,P(5, 7) - 0.1779\,P(10, 2) + 0.1704\,\Delta P(11, 5)$$
$$-\ 0.0747\,P(17, 3) - 0.0942\,P(9, 7)$$

$$\hat{D}_{24} = +\ 295.45 + 0.2037\,\lambda + 0.0601\,\Delta P(9, 3) - 0.4234\,\Delta P(5, 3) - 0.8318\,P(10, 5)$$
$$+\ 0.4815\,\Delta P(10, 6) + 0.4700\,P(12, 6) - 0.2154\,P(17, 3) + 0.5081\,\Delta P(10, 4) + 0.\text{[illegible]}588\,P(11, 1)$$

B.1.4 Equations Using Surface Predictors Only, with Past History (All Zones)*

$$\hat{N}_{12} = -\ 4.3017 + 0.9612\,\Delta\phi - 0.0359\,\lambda + 0.0148\,P(17, 7) - 0.1004\,P(11, 7)$$
$$+\ 0.0458\,P(14, 6) - 0.0572\,\phi + 0.0499\,P(13, 3) + 0.0520\,\Delta P(9, 3)$$

---

*Twelve- and 24-hr predictions only.

$$\hat{E}_{12} = +13.020 + 0.6839\Delta\lambda + 0.0263\,P(13,11) - 0.1078\,P(10,2) + 0.1472\,P(12,6) - 0.0201\,\lambda - 0.0343\,P(15,3) - 0.0823\,\Delta P(8,6) + 0.0485\,\phi + 0.0366\,P(5,7) + 0.0887\,\Delta P(11,5) - 0.0834\,P(10,6)$$

$$\hat{D}_{12} = +\,87.703 + 0.1519\,\Delta P(9,5) + 0.0707\,\lambda - 0.7367\,P(10,5) + 0.6389\,P(11,5) - 0.1822\,\Delta P(5,3) + 0.3093\,\Delta P(10,4) - 0.8537\,\Delta\phi + 0.2994\,\Delta P_c$$

$$\hat{N}_{24} = +\,7.7605 + 1.2399\,\Delta\phi - 0.0683\,\lambda + 0.0813\,P(17,7) - 0.1776\,P(11,7) + 0.0646\,\Delta P(15,5) - 0.1017\,\phi + 0.1002\,P(14,4) + 0.1133\,\Delta P(11,9) - 0.1203\,\Delta P(10,6) + 0.1161\,\Delta P(11,3)$$

$$\hat{E}_{24} = -\,0.6236 + 1.1414\,\Delta\lambda + 0.0678\,P(13,11) - 0.1650\,P(13,1) - 0.0496\,\lambda + 0.1121\,\phi + 0.1400\,P(13,7) + 0.0792\,P(3,3) - 0.0564\,P(17,3) - 0.1295\,P(9,3) + 0.1230\,\Delta P(13,5) - 0.1124\,\Delta P(8,6) + 0.0585\,P(6,8)$$

$$\hat{D}_{24} = +\,368.81 + 0.1665\,\lambda + 0.2518\,\Delta P(9,3) - 0.3945\,\Delta P(5,3) - 1.1104\,P(10,5) + 0.5362\,\Delta P_c + 0.6422\,P(11,5) + 0.4337\,\Delta P(10,5) - 0.9934\,\Delta\phi + 0.2304\,P(11,7) - 0.1501\,P(17,3)$$

B.1.5 Equations Using Derived Predictors, without Past History (All Zones)*

$$\hat{N}_{24} = +\,77.026 + 0.5702\,v_7 - 0.0725\,\lambda + 0.0368\,P(16,6) - 0.0163\,A_{H7}(9,6) + 0.6157\,\Delta u_7 - 0.1218\,P(10,6) + 0.1569\,\zeta_T(8,8) + 0.0499\,Z(14,4) - 0.0166\,H\,(6,8) - 0.0493\,H_7(12,2)$$

$$\hat{E}_{24} = +\,8.2071 - 0.6142\,u_7 + 0.0205\,Z(12,10) + 0.0158\,A_{H5}(9,7) - 0.0426\,\Delta Z(6,5) - 0.0248\,Z(11,1) + 0.4823\,v_7 - 0.1760\,\Delta\zeta_T(10,9) + 0.0610\,P(5,5) - 0.0640\,P(17,3) + 0.0355\,A_{\zeta T}(13,4)$$

$$\hat{N}_{24} = +\,457.88 - 0.5449\,|V| + 0.1336\,\lambda + 0.1093\,\Delta Z(9,8) - 0.4647\,P(10,5) + 0.0758\,\Delta Z(10,3) + 0.0356\,A_H\,(6,4) - 0.1696\,A_{\zeta T}(9,10) + 0.0513\,A_H\,(9,7) + 0.4407\,\Delta P(9,6) - 0.8333\,v_7' + 0.2719\,\Delta P(10,3)$$

B.1.6 Equations Using Derived Predictors, with Past History (All Zones)*

$$\hat{N}_{24} = +\,100.07 + 0.9163\,\Delta\phi + 0.0559\,Z(14,4) - 0.0119\,Z(7,7) - 0.0532\,\lambda + 0.1685\,\zeta_T(8,8) - 0.1192\,P(10,6) - 0.0588\,H_7(12,2) + 0.4108\,\Delta u_7 + 0.1687\,|V| + 0.1182\,\zeta_T(14,2)$$

*Twenty-four-hour predictions only.

$$\hat{E}_{24} = +\ 101.34 + 0.9242\,\Delta\lambda - 0.2744u + 0.0157\,Z(12,10) + 0.1687\,v_7 - 0.0045\,H\ (6,8) - 0.1505\,\Delta\zeta_T(10,9) - 0.1523\,P(13,1) + 0.0129\,A_H(9,7) - 0.0369\,H_7(12,2) + 0.7737\,v_7 + 0.0640\,P(5,9) - 0.4488\,v'_7 + 0.0196\,A_{H7}(6,9)$$

$$\hat{D}_{24} = +\ 459.74 - 0.5237\,|V| + 0.1378\,\lambda + 0.1146\,\Delta Z(9,8) - 0.4671\,P(10,5) + 0.0730\,\Delta Z(10,3) + 0.0348\,A_H\ (6,4) + 0.1851\,\Delta P_c - 0.1660\,A_{\zeta T}(9,10) + 0.0490\,A_H\ (9,7) + 0.3887\,\Delta P(9,6) - 0.7968\,v'_7 + 0.2479\,\Delta P(10,3)$$

B.2 Summer Cyclones

B.2.1 Equations Using Both Surface and Upper-air Predictors, without Past History (All Zones)*

$$\hat{N}_{12} = +\ 143.86 - 0.1334\,\Delta P(9,7) - 0.0298\,P(15,7) - 0.0579\,P(11,7) + 0.0093\,\Delta P(7,5) + 0.0025\,\Delta P(11,9) - 0.0194\,\lambda - 0.0442\,P(9,1) - 0.0197\,Z(9,7) + 0.0550\,Z(13,5) - 0.0207\,H(13,3) + 0.0424\,P(15,9) - 0.0157\,H(9,5) - 0.0500\,P(5,1) - 0.1096\,\Delta P(10,5) + 0.0875\,\Delta P(11,3)$$

$$\hat{E}_{12} = +\ 64.417 + 0.0002\,Z(11,9) - 0.0358\,Z(9,3) + 0.0448\,Z(11,7) - 0.0201\,H(13,5) + 0.0074\,Z(3,7) - 0.0588\,P(11,1) + 0.0724\,\Delta P(11,7) - 0.0757\,\Delta P(9,5) + 0.0240\,\Delta Z(11,3) - 0.0164\,\Delta Z(7,5)$$

$$\hat{D}_{12} = +\ 68.976 + 0.2442\,\Delta P(9,5) - 0.5834\,P(10,5) + 0.5122\,P(11,5) - 0.1222\,\Delta P(7,5) + 0.2946\,\Delta P(10,5) - 0.1762\,\Delta P(7,3)$$

$$\hat{N}_{24} = +\ 223.78 + 0.0497\,P(15,7) - 0.1484\,P(11,7) - 0.2225\,\Delta P(9,7) + 0.1030\,\Delta P(7,5) - 0.0363\,\lambda - 0.1190\,P(9,1) - 0.0501\,H(9,7) + 0.0817\,Z(13,5) + 0.0147\,Z(15,11) - 0.0478\,Z(7,1) + 0.0306\,H(5,1) - 0.1760\,\Delta P(10,5) - 0.0292\,H(13,3) + 0.1469\,\Delta P(11,3)$$

$$\hat{E}_{24} = +\ 106.68 + 0.0181\,Z(11,9) - 0.0810\,Z(9,3) + 0.0475\,Z(11,7) + 0.0193\,Z(3,7) - 0.0342\,H(13,5) - 0.1023\,P(15,3) + 0.0273\,Z(11,5) + 0.0489\,\Delta Z(11,7) - 0.0359\,\Delta Z(7,5)$$

$$\hat{D}_{24} = +\ 189.8 - 0.9737\,P(10,5) + 0.6694\,\Delta P(10,5) + 0.7810\,P(11,5) - 0.2985\,\Delta P(7,3)$$

---

*Twelve- and 24-hr predictions only.

B.2.2 Equations Using Both Surface and Upper-air Predictors, with Past History (All Zones)*

$$\hat{N}_{12} = + 79.151 + 0.4110\,\Delta\phi + 0.0165\,P(15,7) - 0.0864\,P(11,7) - 0.1686\,\Delta P(9,7) - 0.1904\,\Delta\lambda + 0.0436\,\Delta P(13,9) - 0.0166\,\lambda - 0.0790\,P(9,1) + 0.0717\,P(13,3) + 0.0601\,\Delta P(11,3) - 0.0228\,H(9,7) + 0.0226\,Z(13,7)$$

$$\hat{E}_{12} = + 8.8369 + 0.4826\,\Delta\lambda + 0.0034\,Z(11,9) - 0.0299\,Z(9,3) + 0.0321\,Z(11,7) - 0.0649\,\Delta P(9,5) + 0.0802\,\Delta P(13,5) - 0.0656\,\Delta P(9,3) + 0.0098\,\Delta Z(3,7) - 0.0108\,H(13,5)$$

$$\hat{D}_{12} = + 55.373 + 0.2200\,\Delta P(9,5) + 0.4158\,\Delta\lambda - 0.5600\,P(10,5) + 0.5028\,P(11,5) - 0.2317\,\Delta P(7,3) + 0.2558\,\Delta P(10,5)$$

$$\hat{N}_{24} = + 106.00 + 0.4652\,\Delta\phi + 0.0565\,P(15,7) - 0.0594\,P(11,7) - 0.0497\,Z(9,7) + 0.0601\,Z(13,5) + 0.0146\,Z(15,11) - 0.0869\,\phi - 0.0991\,P(5,1) - 0.0247\,H(9,5) - 0.1311\,\Delta P(11,7)$$

$$\hat{E}_{24} = + 4.5897 + 0.5862\,\Delta\lambda + 0.0215\,Z(11,9) - 0.0623\,Z(9,3) + 0.0375\,Z(11,7) - 0.1754\,\Delta P(9,3) + 0.1143\,\Delta P(13,5) + 0.0457\,\Delta Z(11,7) - 0.0326\,\Delta Z(7,5)$$

$$\hat{D}_{24} = + 216.82 - 0.9411\,P(10,5) + 0.4080\,\Delta P(10,5) + 0.6747\,P(11,5) - 0.1632\,\Delta P(7,3) + 0.0688\,P(11,9) + 0.1100\,\Delta P(15,7) - 0.2144\,\Delta\phi + 0.0150\,H(7,7) - 0.0262\,H(11,1) + 0.1169\,\Delta Z(9,5) - 0.1010\,\Delta Z(5,1)$$

B.2.3 Equations Using Surface Predictors Only, without Past History (All Zones)*

$$\hat{N}_{12} = + 33.647 - 0.1288\,\Delta P(10,6) + 0.0830\,P(15,7) - 0.1150\,P(11,7) + 0.1165\,\Delta P(12,8) - 0.1624\,\Delta P(9,7) - 0.0288\,\lambda - 0.1226\,P(9,1) + 0.0918\,\Delta P(8,4) + 0.0896\,P(11,3) + 0.0346\,P(15,11)$$

$$\hat{E}_{12} = + 48.628 + 0.0161\,P(12,8) - 0.0895\,P(11,1) - 0.1745\,\Delta P(8,6) + 0.1988\,\Delta P(11,5) - 0.1271\,P(10,5) + 0.1493\,P(12,6)$$

$$\hat{D}_{12} = + 92.725 + 0.5253\,\Delta P(9,5) - 0.1191\,P(7,5) + 0.0518\,P(10,8) - 0.5604\,P(10,5) + 0.5332\,P(11,5) - 0.2980\,\Delta P(8,4) - 0.1978\,\Delta P(15,3) + 0.1694\,\Delta P(10,4)$$

$$\hat{N}_{24} = - 0.6180 + 0.1330\,P(15,7) - 0.1753\,P(10,6) - 0.0611\,\lambda - 0.2532\,\Delta P(9,7) + 0.1694\,\Delta P(7,5) + 0.0763\,P(15,11) + 0.2037\,P(14,4) - 0.2459\,P(12,6) - 0.2264\,P(9,1) + 0.2411\,P(9,5) + 0.1613\,\Delta P(12,8) - 0.2495\,\Delta P(10,6) + 0.1659\,\Delta P(12,4)$$

*Twelve- and 24-hr predictions only.

$$\hat{E}_{24} = -\ 40.365 + 0.1118P(13,9) - 0.2302P(12,2) - 0.3155\Delta P(8,6) + 0.1695\Delta P(11,7)$$
$$+ 0.3252P(13,5) - 0.0635\lambda + 0.0620P(1,7) + 0.1064P(5,3) + 0.2779\Delta P(11,5)$$
$$- 0.2090P(10,4) - 0.1263P(15,3)$$

$$\hat{D}_{24} = +\ 189.80 - 0.9737P(10,5) + 0.6694\Delta P(10,5) + 0.7810P(11,5) - 0.2985\Delta P(7,3)$$

B.2.4 Equations Using Surface Predictors Only, with Past History (All Zones)*

$$\hat{N}_{12} = +\ 26.565 + 0.6489\Delta\phi - 0.1402\Delta P(10,6) + 0.0700P(15,7) - 0.0942P(11,7)$$
$$- 0.0434\phi + 0.0771\Delta P(12,8) - 0.0982\Delta P(1,3)$$

$$\hat{E}_{12} = +\ 8.3190 + 0.6092\Delta\lambda - 0.1325\Delta P(8,6) + 0.0222P(13,11) - 0.0586P(10,2)$$
$$+ 0.1179P(12,6) + 0.0140\Delta P(12,4) - 0.0922P(10,5) + 0.1231\Delta P(11,5)$$

$$\hat{D}_{12} = +\ 83.916 + 0.6191\Delta P(9,5) - 0.1870P(7,5) + 0.4597\Delta\lambda - 0.1184\Delta P_c + 0.0626P(10,8)$$
$$- 0.2804\Delta P(17,1) - 0.5551P(10,5) + 0.2779P(10,4) + 0.3165P(11,5)$$
$$- 0.2237\Delta P(8,4)$$

$$\hat{N}_{24} = -\ 75.979 + 0.8567\Delta\phi + 0.0990P(15,7) - 0.2140P(11,7) - 0.2568\Delta\lambda$$
$$+ 0.0824P(15,11) + 0.1295\Delta P(13,9) - 0.2187\Delta P(9,7) + 0.1684\Delta P(7,5)$$
$$- 0.0799\phi + 0.1113P(14,4)$$

$$\hat{E}_{24} = +\ 11.630 + 1.0631\Delta\lambda + 0.1002P(13,11) - 0.1772\Delta P(8,6) - 0.2987P(12,2)$$
$$+ 0.1867P(13,5) + 0.1556\Delta P(12,6) - 0.0395\lambda$$

$$\hat{D}_{24} = +\ 189.80 - 0.9737P(10,5) + 0.6694\Delta P(10,5) + 0.7810P(11,5) - 0.2985\Delta P(7,3)$$

*Twelve- and 24-hr predictions only.

APPENDIX C. PROCEDURE FOR MANUAL OPERATIONAL PREDICTION

C.1 Construction of Worksheets

The following example demonstrates the procedure for making an operational forecast of the displacement and change in central pressure of winter cyclones for 12, 24, and 36 hr. The case to be illustrated is hypothetical, but gives a general idea of how worksheets for other equations can be derived. Although other equations may be recommended for specific situations (Section 7.0), the unstratified (base-technique) set of equations (Section B.1.1.5) was chosen for this example.

Besides arranging the predictors on the worksheets in a form convenient for tabulation and computation, the following modifications are desirable in preparing worksheets.

(a) Transform the predictands so that the final result of the computation yields the forecast latitude, longitude, and central pressure. This can be done easily by adding the initial latitude and central pressure to the $\hat{N}$- and $\hat{D}$-equations of Appendix B, which in effect is making these initial conditions predictors multiplied by a coefficient of 1. If an initial condition is already a predictor, its coefficient is modified by adding 1.000 to it. Thus for $\hat{D}_{12}$ (12-hr prediction of central pressure), P(10,5), which has a coefficient of -0.5929 in Section B.1.1.5, becomes 0.4071. The longitude transformation is a little more involved. There, it is necessary to convert the result from degrees of latitude to degrees of longitude before adding on the initial longitude. Thus the final longitude can be expressed by

$$\text{Forecast longitude} = \lambda + \hat{E} \sec \frac{\phi + \phi_F}{2}, \tag{C-1}$$

where λ is the initial longitude in degrees of longitude (negative if east longitude), $\hat{E}$ is the predicted eastward displacement in degrees of latitude, ϕ is the initial latitude in degrees of latitude, and ϕ_F is the forecast latitude in degrees of latitude.

(b) Transform the 500-mb height and 1000–500-mb thickness predictors and their time changes to the recently adopted decameter system by multiplying each by 3.2808.

(c) When a 1000–500-mb thickness chart is unavailable, the predictor can be computed accurately enough by converting the sea-level pressure to 1000-mb height by use of the hypsometric formula. If a mean temperature of 0°C between the surface and 1000 mb is assumed (which is reasonable for winter situations), the following equation can be used:

$$H = Z - 0.8\,(P - 1000), \tag{C-2}$$

where H is the 1000–500-mb thickness in decameters, Z is the 500-mb height in decameters, and P is the sea-level pressure in millibars. Base-technique worksheets, shown in Figs. C-1 through C-4, are for use when pressure data are in millibars and height data are in decameters (Dm).

NORTH AMERICAN CYCLONE PREDICTORS

(BASE TECHNIQUE)

t_0 = ______ Z ______ 196__

Surface Predictors (mb)

	t_0	t_{-12}	ΔP
Lat(ϕ)	42.3		
Long(λ)	90.2		
P(11,9)	1016		
P(5,7)	1018		
P(7,7)	1017		
P(9,7)	1013	1013	0
P(11,7)	1013	1015	-2
P(13,7)	1016		
P(15,7)	1015		
P(5,5)	1018		
P(7,5)	1015	1011	4
P(9,5)	1007	1009	-2
P(10,5)	1001		
P(11,5)	1007	1014	-7
P(3,3)	1018	1018	0
P(9,3)	1011	1012	-1
P(13,3)	1017		
P(15,3)	1019		
P(5,1)	1017		
P(11,1)	1015		
P(13,1)	1017		

500-mb Predictors (Dm)

	t_0	t_{-12}	ΔZ
Z(13,11)	521		
Z(15,11)	525		
Z(9,9)	528	528	0
Z(11,9)	527		
Z(13,9)	529		
Z(7,7)	539	539	0
Z(9,7)	535		
Z(11,7)	538	539	-1
Z(13,7)	542		
Z(15,7)	545		
Z(7,5)	548	549	-1
Z(9,5)	543	550	-7
Z(11,5)	549	553	-4
Z(13,5)	555		
Z(15,5)	558		
Z(7,3)	561	562	-1
Z(9,3)	559	563	-4
Z(11,3)	563		
Z(13,3)	567	566	1
Z(9,1)	572		
Z(11,1)	574		

Thickness (1000-500 mb) Predictors

H(7,7) = Z(7,7) - 0.8 [P(7,7) - 1000] = 525

H(9,7) = Z(9,7) - 0.8 [P(9,7) - 1000] = 524

H(7,5) = Z(7,5) - 0.8 [P(7,5) - 1000] = 536

H(11,5) = Z(11,5) - 0.8 [P(11,5) - 1000] = 543

H(9,3) = Z(9,3) - 0.8 [P(9,3) - 1000] = 550

H(13,3) = Z(13,3) - 0.8 [P(13,3) - 1000] = 554

H(11,1) = Z(11,1) - 0.8 [P(11,1) - 1000] = 562

ΔH(9,5) = ΔZ(9,5) - 0.8 [ΔP(9,5)] = -4.6

ΔH(11,5) = ΔZ(11,5) - 0.8 [ΔP(11,5)] = 1.7

Fig. C-1. Data-tabulation worksheet.

NORTH AMERICAN CYCLONE PREDICTION (12 HOUR)

LATITUDE

Lat(ϕ)	42.3	X	1.0000
Long(λ)	90.2	X	-0.0428
P(9,7)	1013	X	0.0583
P(11,7)	1013	X	-0.0971
P(5,1)	1017	X	-0.0467
ΔP(9,7)	0	X	-0.1190
ΔP(11,7)	-2	X	-0.0279
ΔP(9,3)	-1	X	0.0836
Z(9,7)	535	X	-0.0938
Z(13,5)	555	X	0.1755
H(13,3)	554	X	-0.0712

SUM OF PRODUCTS -40.612

CONSTANT ADDITIVE 83.5783

FORECAST LATITUDE 43.0

CENTRAL PRESSURE

Long(λ)	90.2	X	0.0590
P(5,5)	1018	X	-0.0942
P(10,5)	1001	X	0.4071
P(11,5)	1007	X	0.4357
ΔP(9,7)	0	X	0.1863
ΔP(9,5)	-2	X	0.3942
Z(9,9)	528	X	0.1010
Z(13,9)	529	X	-0.0387
ΔZ(9,3)	-4	X	0.1506
H(11,1)	562	X	-0.1073
ΔH(9,5)	-4.6	X	0.1804

SUM OF PRODUCTS 726.02

CONSTANT ADDITIVE 272.183

FCST CENTRAL PRESSURE 998

LONGITUDE

P(5,7)	1018	X	0.0254
P(13,7)	1016	X	0.0314
P(11,5)	1007	X	0.0927
P(9,3)	1011	X	-0.1075
P(15,3)	1019	X	-0.0380
ΔP(7,5)	4	X	-0.1189
Z(11,9)	527	X	0.0440
Z(9,1)	572	X	-0.0180
ΔZ(11,7)	-1	X	0.0925
ΔZ(7,3)	-1	X	-0.0505
H(7,7)	525	X	-0.0384
H(9,7)	524	X	0.0646
H(9,3)	550	X	-0.0741
ΔH(9,5)	-4.6	X	-0.0515

SUM OF PRODUCTS -10.75

CONSTANT ADDITIVE 6.5083

(1) Total = -4.241

(2) 1/2 (initial + fcst lat.) 42.7

(3) Sec (2) 1.367 X (1) = -5.8

(4) Initial Long. (λ) 90.2

(5) FORECAST LONG. [(3) + (4)] 84.4

	FORECAST	CONVENTIONAL OR SUBJECTIVE	VERIFICATION
Latitude	43.0		
Longitude	84.4		
Central Pressure	998		

Fig. C-2. Twelve-hour-prediction worksheet.

NORTH AMERICAN CYCLONE PREDICTION (24 HOUR)

LATITUDE

Lat(ø)	42.3	X	1.0000
Long(λ)	90.2	X	-0.0787
P(11,9)	1016	X	-0.0493
ΔP(11,7)	-2	X	-0.0971
ΔP(9,3)	-1	X	0.1026
Z(7,7)	539	X	0.0354
Z(9,7)	535	X	-0.2244
Z(13,7)	542	X	0.0863
Z(13,5)	555	X	0.1188
Z(15,5)	558	X	0.0476
ΔZ(7,7)	0	X	-0.1464
ΔZ(13,3)	1	X	0.0883

SUM OF PRODUCTS 23.588

CONSTANT ADDITIVE 20.5766

FORECAST LATITUDE 44.2

CENTRAL PRESSURE

Long(λ)	90.2	X	0.1737
P(5,5)	1018	X	-0.1437
P(10,5)	1001	X	0.2071
P(11,5)	1007	X	0.5390
ΔP(9,5)	-2	X	0.4003
ΔP(9,3)	-1	X	0.1026
Z(11,1)	574	X	-0.1217
ΔZ(9,9)	0	X	0.4669
ΔZ(9,5)	-7	X	0.2011
H(9,7)	524	X	0.2566
H(11,5)	543	X	-0.2205

SUM OF PRODUCTS 562.02

CONSTANT ADDITIVE 434.380

FCST CENTRAL PRESSURE 996

LONGITUDE

P(13,7)	1016	X	0.0914
P(13,1)	1017	X	-0.0800
ΔP(7,5)	4	X	-0.1322
Z(15,11)	525	X	0.0305
Z(11,9)	527	X	0.1040
Z(11,5)	549	X	0.1070
Z(11,3)	563	X	-0.2093
Z(9,1)	572	X	0.0020
ΔZ(11,7)	-1	X	0.1142
ΔZ(7,3)	-1	X	-0.1325
H(7,5)	536	X	-0.0787

SUM OF PRODUCTS -19.32

CONSTANT ADDITIVE 10.1768

(1) Total -9.1

(2) 1/2 (initial + fcst. lat.) 43.3

(3) Sec (2) 1.367 X (1) = -12.50

(4) Initial Long. (λ) 90.2

(5) FORECAST LONG. [(3) + (4)] 77.7

	FORECAST	CONVENTIONAL OR SUBJECTIVE	VERIFICATION
Latitude	44.2		
Longitude	77.7		
Central Pressure	996		

Fig. C-3. Twenty-four-hour prediction worksheet.

NORTH AMERICAN CYCLONE PREDICTION (36 HOUR)

LATITUDE

Lat(φ)	42.3	X	1.0000
Long(λ)	90.2	X	-0.1206
P(9,7)	1013	X	0.1368
P(11,7)	1013	X	-0.2193
P(15,7)	1015	X	0.0619
Z(9,7)	535	X	-0.2218
Z(15,7)	545	X	0.0666
Z(13,5)	555	X	0.1991
Z(15,5)	558	X	0.0289
ΔZ(7,7)	0	X	-0.1886
ΔH(11,5)	1.7	X	0.1211

SUM OF PRODUCTS 55.14

CONSTANT ADDITIVE -9.6302

FORECAST LATITUDE 45.5

CENTRAL PRESSURE

Long(λ)	90.2	X	0.1900
P(5,7)	1018	X	-0.1426
P(13,7)	1016	X	0.3786
P(10,5)	1001	X	0.2955
ΔP(11,7)	-2	X	0.2990
ΔP(3,3)	0	X	-0.3200
Z(9,9)	528	X	0.1955
Z(13,3)	567	X	-0.3327
Z(11,1)	574	X	0.0135
ΔZ(9,9)	0	X	0.3937
ΔZ(9,5)	-7	X	0.3123
ΔH(11,5)	1.7	X	-0.2982

SUM OF PRODUCTS 471.47

CONSTANT ADDITIVE 523.605

FCST CENTRAL PRESSURE 995

LONGITUDE

P(13,7)	1016	X	0.1647
P(13,1)	1017	X	-0.1587
Z(13,11)	521	X	-0.0331
Z(15,11)	525	X	0.0896
Z(11,9)	527	X	0.1680
Z(11,3)	563	X	-0.1394
Z(9,1)	572	X	-0.0682
ΔZ(7,5)	-1	X	-0.2001
H(7,5)	536	X	-0.0820

SUM OF PRODUCTS -36.98

CONSTANT ADDITIVE 25.0906

(1) Total = -11.89

(2) 1/2 (initial + fcst lat.) 44.0

(3) Sec (2) 1.390 X (1) = -16.53

(4) Initial Long. (λ) 90.2

(5) FORECAST LONG. [(3) + (4)] 73.7

	FORECAST	CONVENTIONAL OR SUBJECTIVE	VERIFICATION
Latitude	45.5		
Longitude	73.7		
Central Pressure	995		

Fig. C-4. Thirty-six-hour-prediction worksheet.

Construction of a grid overlay similar to that in Fig. 2-2 may be facilitated by recalling that the grid has the same spacing between points as the JNWP grid, i.e., 1 in. on a polar-stereographic projection, with standard parallel at 60°N for a map scale of 1:15,000,000.

C.2 Use of Worksheets

C.2.1 Data-tabulation Worksheet

Using the grid overlay to locate the appropriate points, enter the sea-level pressures and 500-mb heights from the current charts (in the correct units and format) under t_0. [To position the grid overlay, place the point $(k, l) = (10,5)$ over the t_0-position of the cyclone and orient so that the line $k = 10$ coincides with the meridian passing through the t_0-position.]

Determine the t_{-12} entries for the required points from the 12-hr-old charts. [Maintain the gridpoint $(k,l) = (10,5)$ over the t_0-position of the cyclone; the values recorded for t_{-12} are to be used to obtain time changes of heights and pressures at the several points.]

Determine the necessary Δ's.

Determine the 1000–500-mb thicknesses at the required points either by using the formulae given at the bottom of the page or by reading the values directly from the analyzed 1000–500-mb thickness chart (using the grid as an overlay) or from a nomogram.

C.2.2 Prediction Worksheets

Enter on each of the three prediction worksheets the appropriate parameters from the data-tabulation worksheet.

To determine the forecast latitudes:

(a) Compute the products of the individual parameters and their respective coefficients.

(b) Sum these products.

(c) Add the "constant additive" to this sum; the total thus derived is, in each case, the forecast latitude.

To determine the forecast longitudes:

(a) Compute the products of the individual parameters and their respective coefficients.

(b) Sum these products.

(c) Add the "constant additive" to this sum; enter the total thus derived on line 1 on the right-hand side of the page. [This is the forecast westward (+) or eastward (-) movement in degrees of latitude.]

(d) To convert the forecast movement to degrees of longitude, take one-half the sum of the initial latitude (ϕ) and the forecast latitude (determined above). This gives a mean latitude.

(e) Using a secant table, determine the secant ("sec") of this mean latitude. Enter the value on line 3 on the right-hand side of the page in the blank following the words "sec (2)."

(f) Multiply this secant value by the value entered on line 1, i.e., by the total cited in (c) above. Enter this product at the far right of line 3.

(g) Enter on line 4 the initial longitude of the cyclone at time t_0. Note that east longitude is entered with a minus sign, west longitude with a plus.

(h) Algebraically add together the values on lines 3 and 4, and enter this total on line 5; this is the forecast longitude. (Thus, the value on line 3 is a forecast longitude change; when added to the original longitude, the forecast longitude is obtained.)

To forecast the central pressure of the cyclone, use the same procedure, but with values of pressure.

Unusual displacements or changes in pressure should be recomputed.

Enter the forecast latitude, longitude, and central pressure, the conventional or subjective forecasts, and the verification in the box at the bottom of the page.